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Technical and Economic Causes of U.S. Corn and Soybean Yield Changes

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ABSTRACT

Since 1930 U.S. corn yields have quadrupled and U.S. soybean yields have doubled. To explain these yield increases, crop yield forecasting models often use year as a single surrogate variable to reflect the composite effect of technological change. The yield impact of applied technology has not been smooth and constantly increasing over time, but variable between years because of changes in the available stock of technology and changes in economic and institutional factors influencing technology adoption. Regional differences occur in the adoption periods and the potential yield responses for fertilizers, genetic improvement in seeds, pesticides and changes in the cultural practices of plant density and double cropping. The yield influencing natural resource developments of drainage, irrigation and soil conservation change over time with the depreciation or replacement of existing systems.

Key Words: Technological impacts on crop yield, crop yield modeling, corn yield trend, soybean yield trend.

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TECHNICAL AND ECONOMIC CAUSES OF U.S. CORN AND
SOYBEAN YIELD CHANGES

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*AgRISTARS is an acronym for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing. It is a multi-agency research program to meet some current and new information needs of the U.S. Department of Agriculture.

AgRISTARS
Yield Model Development
Project

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Technical and Economic Causes of U.S.
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INTRODUCTION

Agricultural production and crop yields have always been subject to wide variability due to the vagaries of weather. Considerable effort has been devoted to modeling factors influencing crop yields at different points during the growing season which include the current year's weather. The development of such models generally requires a relatively long time series of data in order to measure the effects of wide ranges in weather on crop yield. A major obstacle in developing such models is the effect of technology and other non-climatic factors on yield over the time series. For some growing areas and crops it has been shown that trend as measured by year can explain over 75% of the time-series yield variations [44]. A more definitive explanation of this trend component is desired for improving models for use in forecasting crop yields.

Modelers have questioned the validity of using year as a surrogate variable for all non-weather impacts on yield. The development and application of technology does not necessarily occur in a smooth and continuously increasing pattern over time. Shaw and Durost hypothesized that the pattern of yield increases is one of plateaus, with technological improvements making possible the movement from one plateau to another [67]. Others have hypothesized that the dynamics of prices, agricultural policy, resource availability, weather and management variables result in year to year fluctuations in the use and application of technological factors influencing yield and that an assumption of a smooth trend is an inadequate estimate of the technology component. A more accurate specification of the technology component which can reflect both adoption and plateau periods, as well as year to year fluctuation, is needed to assess weather impacts on yields.

Most models used to forecast the impact of weather and climate on crop yield are developed using twenty to fifty years of weather and yield data. Over such a time span there has been a significant increase in both corn and soybean yields which must be taken into account in the modeling process. This increase has been broadly attributed to technology. If time as a surrogate variable for technology is to be replaced in yield forecasting models, greater knowledge of crop production inputs, management, prices and agricultural policies needs to be acquired.

The purpose of this report is to define the technology component for use in crop yield models and to identify some technological and economic variables influencing U.S. corn and soybean yields. This study contributes broad background material useful in developing further research on technological change, its influence on crop yields and data needs for further modeling efforts. This information will be useful in the development of alternative technology variables or an improved specification of a trend variable in other AgRISTARS Yield Model Development tasks.

The first section of this report assesses national and regional corn and soybean production trends and variation. Major U.S. corn and soybean production areas are identified along with their yield trends and variation in yields. The second section conceptually defines technology as a component of an aggregate crop yield model. Physical, economic, and institutional dimensions of a crop production system are used to define the technology component and to identify various elements which potentially interact within the system to effect yield.

The next two sections identify important technological and economic factors which have influenced corn and soybean yields. These include production inputs and cultural practices which can be specifically related to corn or soybeans and natural resource developments which improve land productivity for most crops. The adoption period and trends in use are illustrated as well as some indication of their potential yield impact as reported in experimental or site specific research studies. The final section highlights the needs for further investigation of the technological component in crop yield models.

PRODUCTION TRENDS AND VARIABILITY

During the past fifty years there have been significant changes in both the trend and the year to year variation in corn and soybean production. The national trend for production of both crops has been upward; since 1930, however, wide fluctuations in acreage and yield have occurred between production regions as well as between years. Acreage and yield variability at the national and regional levels is discussed in this section of the report.

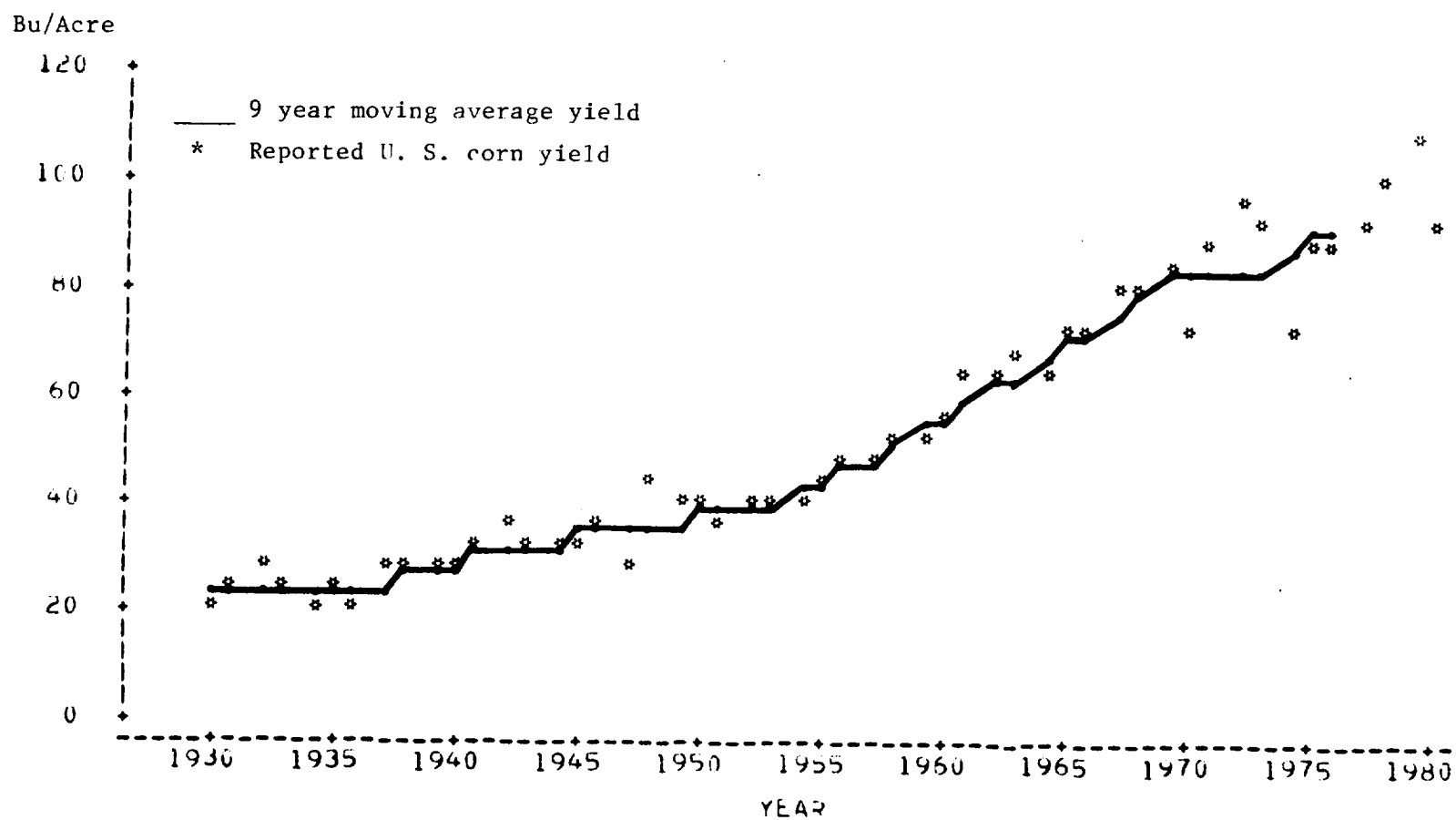
Corn

National Trend

Corn production in the U. S. has gradually expanded since the mid-1930's. National production rose from approximately 2.0 billion bushels in the mid-1930's to record levels of 7.9 and 8.1 billion bushels in 1979 and 1981, respectively. This expansion can be attributed to increases in per acre yields. The peak harvested acreage of over 100 million occurred in the early 1930's. Although wide fluctuations in acreage occurred, the general trend in the next 35 years was downward. The 55 million harvested acres in 1969 were the lowest reported since 1875. From 1969 to 1976, however, acreage increased somewhat and since 1976 it has remained between 71 and 75 million acres.

The most dramatic aspect of corn production in the last fifty years and more specifically the last thirty years has been the increases in yield as shown in Figure 1. Prior to 1930 there was little trend that can be associated with yields. A national average yield of 29.4 bushels per acre was reported

Figure 1. U. S. corn yield trend, 1930 to 1980.



in 1872. This record was broken only six times in the next 68 years.^{1/} However, since the low yields of the early 1930's, the yield trend has been upward, with the frequent occurrence of new record high yields. Fifteen new records were set in the last thirty years (1950-1980).

During the fifty years from 1931 to 1980, the national yields ranged from a low of 18.6 bushels per acre in 1934 to a record high of 109 bushels per acre in 1979 and 1981. Using a nine year moving average to illustrate the trend component, it can be seen in Figure 1 that there has been a steady increase in trend yield since 1932. Table 1 illustrates the number of years associated with each 10 bushel increase in the trend yield. From the time estimates were begun in 1866, until 1940, the nine year moving average corn yield was between 20 and 30 bushels per acre. Since 1953 an additional 10 bushels per acre have been added to the national yield trend every three to six years.

Table 1. Number of years in U.S. corn yield trend associated with each ten bushel increase in yield, 1866-1975^{1/}

Change in trend yield ^{1/} (bushels/acre)	Inclusive years	Number of years
21-30	1866-1940	74
31-40	1941-1952	12
41-50	1953-1958	6
51-60	1959-1961	3
61-70	1962-1965	4
71-80	1966-1969	4
81-90	1970-1975	6

^{1/} Trend yield is measured as a nine year moving average from 1866 to 1980. Source: Reference No. 77.

It is of interest to note that during the forty-six year period (1930-1976) reported in Figure 1, the actual yield was within ten percent of the trend yield in 36 years. Yield departures of greater than 10 percent above the trend occurred in 1932, 1937, 1942, 1948 and 1972. The largest negative departures from trend occurred in 1934, 1936, 1947, 1970 and 1974 which were drought years except 1970 which was a "corn blight" year.

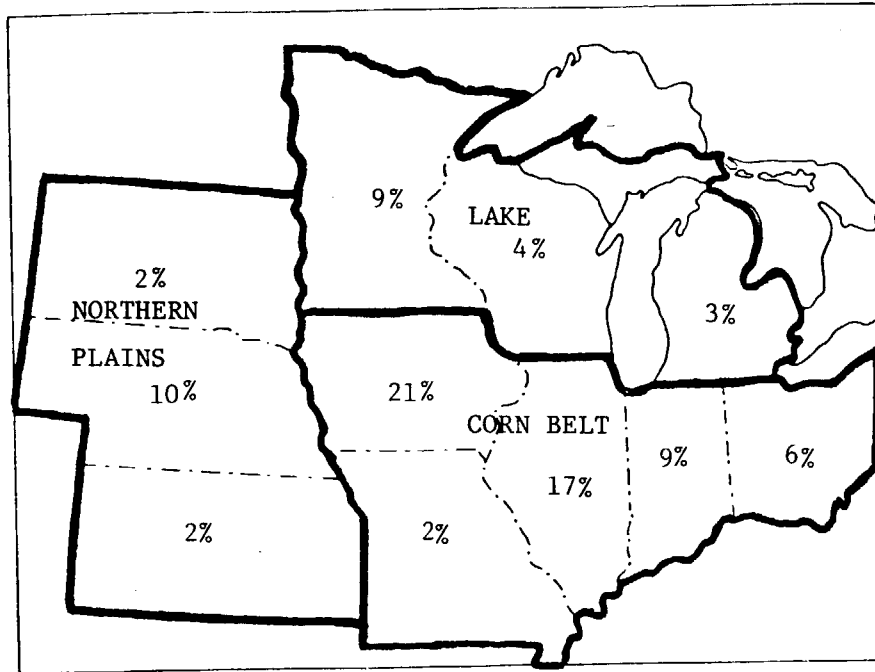
Regional Trends

Several natural resource limitations have confined most of the nation's corn production to eleven states in the North Central section of the country. Figure 2 indicates the 1978 to 1980 mean percentage of national corn production for each of these states. For this report three major producing areas are investigated; they are delineated in Figure 2. These areas are the Corn Belt, Lake and the Northern Plains.^{2/} The natural resource base of soils and

^{1/} National corn yields were 29.5 in 1889, 29.6 in 1891, 30.0 in 1896, 30.9 in 1905, 31.7 in 1906 and 30.3 in 1920 [76].

^{2/} The Northern Plains as used in this report includes S. Dakota, Nebraska and Kansas.

Figure 2. Major U. S. corn producing regions and mean percent of national production by State, 1978-1980.



weather in the Corn Belt allows large acreages to be planted to corn with consistently high yields. The Lake Region is somewhat more limited in its resource base because shortness of growing season becomes a limiting factor and restricts production to the southern portions of those states. Arid conditions in the Northern Plains limit corn production to the eastern sections or to areas where soil moisture can be supplemented through irrigation.

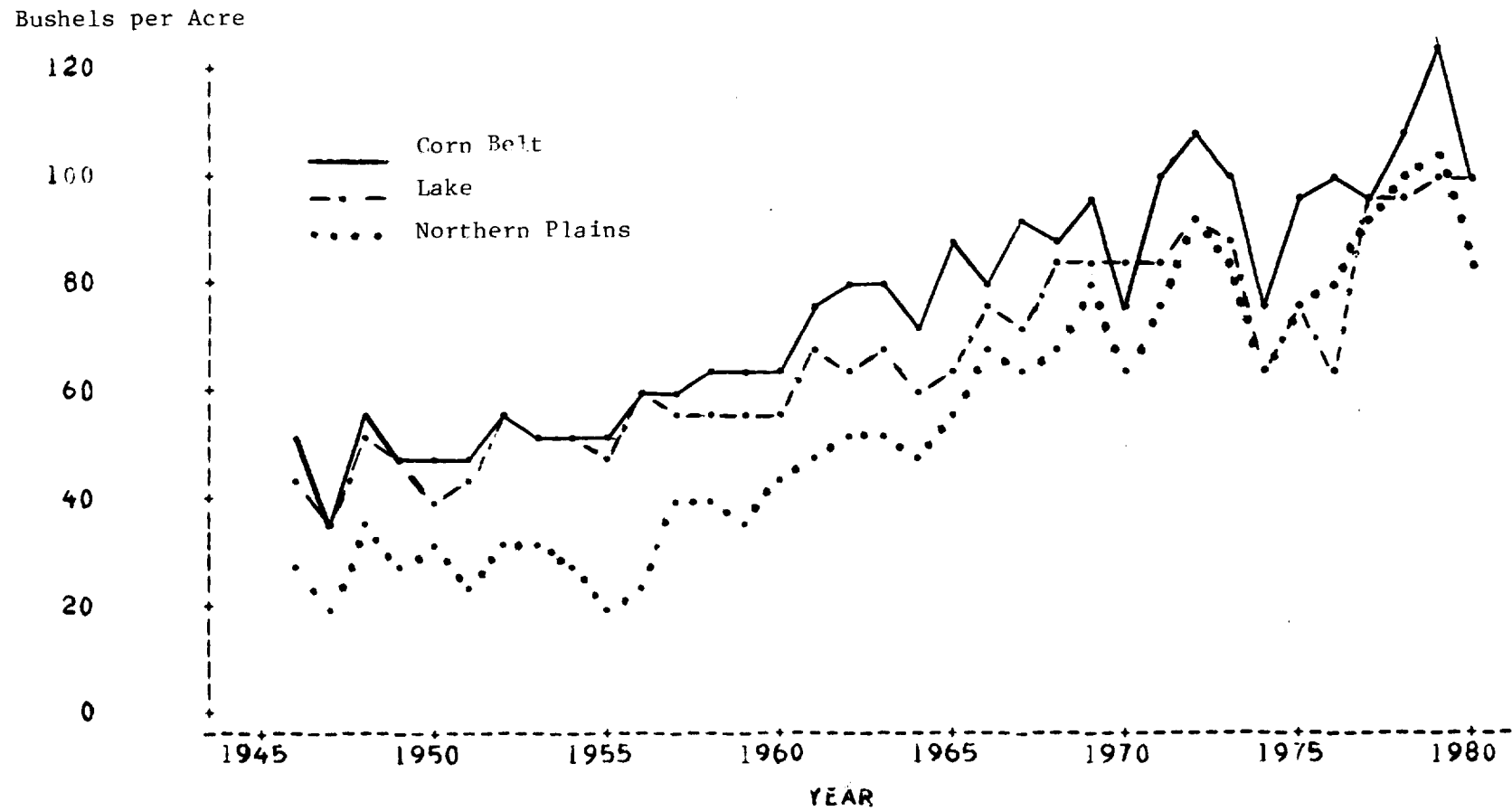
For this report the Corn Belt Region includes Ohio, Indiana, Illinois, Iowa and Missouri, since this area has consistently produced over half of the nation's corn supply. From 1945 to 1965 the proportion of the total U.S. crop produced in these five states increased from 50 to almost 65 percent. Since 1965 the proportion has declined due to expanded production in the Lake and Northern Plains Regions, and the 1978 to 1980 mean proportion produced in the five Corn Belt states was 55 percent. The Lake Region includes Michigan, Wisconsin and Minnesota. The proportion of national production from these three states has been quite variable, ranging from only 9.5 percent in 1950 to over 18 percent in 1980. Over the last three years (1978-80) the Lake Region has produced on the average 16 percent of total U.S. corn supply. Like the Lake Region, the Northern Plains is also a marginal crop producing area. The proportion of national production from South Dakota, Nebraska and Kansas has ranged from 18 percent in 1944 to 7 percent in 1955. For the 1978 to 1980 period, these Plains states produced an average of 14 percent of the U.S. corn supply.

Yields since 1945 for the three major corn producing regions are plotted in Figure 3. Corn yield trends have been upward in all regions, but yield levels and variability are quite different among regions. Over the 35 year period, the Lake Region averaged 9 bushels per acre lower than the Corn Belt, and the Northern Plains' yields were 20 bushels per acre lower than the Corn Belt's yields. When only the last fifteen years of yields are averaged, the yield spread is greater for the Lake Region but less for the Northern Plains. Since 1965 the Northern Plains yields averaged 17.7 bushels less than the Corn Belt yields, while the Lake Region averaged 13.7 bushels per acre less than yields in the Corn Belt.

The relative yield variability for these producing areas is assessed using the statistics of standard deviation (S) and coefficient of variation (C.V.). The standard deviation is a measure of central tendency or the dispersion of data points around the average. One standard deviation above and below the average includes two-thirds of all observations. The standard deviation is measured in the same units as the data, i.e., bushels per acre. The coefficient of variation is expressed as a ratio or percent and allows comparison between different measurement units. The C.V. is calculated as the standard deviation divided by its mean.

The coefficient of variation can be used to indicate the relative variability (or stability) between regions. For example, the standard deviation in yield may be 10 bushels per acre in two states. However, the average yield in one state may be 100 bushels per acre and in the other state only 50 bushels per acre, resulting in C.V.'s of 10 percent and 20 percent, respectively, for the two states. The lower C.V. indicates less variability in yield and that state can be considered as a more stable yielding area than one with a higher C.V.

Figure 3. Corn yields per harvested acre, Corn Belt, Lake and Northern Plains Regions, 1945 to 1980.



As indicated in Table 2, corn yield variability is the greatest in the Northern Plains Region. Yield variability as indicated by the coefficient of variation has been less over the 1965 to 1979 period than it was in the preceding twenty year period. In all states except South Dakota and Minnesota a reduction in the C.V. occurred between the 1944-64 and 1965-79 time periods. The reduction in yield variability is most notable in Kansas and Nebraska.

Table 2. Corn yield variability in the Corn Belt, Lake and Northern Plains Regions, by the periods 1944-1964 and 1965-1979

Region and State	Standard Deviation		Coefficient of Variation	
	1944-64	1965-79	1944-64	1965-79
	- - Bushels/Acre - -		- - - Percent - - -	
Corn Belt	12.0	12.4	20.8	13.0
Ohio	10.3	12.4	17.7	13.7
Indiana	12.1	12.8	20.5	13.4
Illinois	13.1	14.6	21.3	14.3
Iowa	12.7	13.9	21.8	14.4
Missouri	11.4	14.1	26.3	18.6
Lake	8.9	12.3	17.1	15.0
Michigan	11.1	9.6	23.2	12.6
Wisconsin	10.1	11.2	17.2	12.9
Minnesota	8.6	14.8	17.0	18.1
Northern Plains	9.7	14.5	28.2	18.7
South Dakota	7.6	13.0	25.3	26.8
Nebraska	12.6	14.8	33.0	16.9
Kansas	11.4	16.4	35.3	18.8

Soybeans

National Trends

Soybeans were not a crop of much national significance until the mid-1940's. Soybean production increased tremendously from 1950 to 1980 and gained recognition as the second most valuable crop produced in the U.S. In 1940, U.S. soybean production was only 78 million bushels. New record levels of production were set in thirty of the next forty years. The 1979 record of nearly 2.3 billion bushels is almost thirty times the 1940 production level.

These increases in production were achieved by both increases in acreages and yields. A significant upward trend in soybean acreage occurred during most of the 1940 to 1980 time period. From 1940 to 1972 acreage increased on the average of 1.3 million acres each year. In 1973, acreage took a 10 million acre jump. This was followed by a 6.3 million acre decline over the next three years and then from 1976 to 1980 soybean acreage increased over 21 million acres. The 1979 record of 70.9 million acres was almost equal to the corn acreage of that year.

The increases in soybean yields have not been as dramatic as those for corn. The national soybean yield trend is illustrated in Figure 4. The nine-year moving average yield from 1934 to 1976 increased only 12 bushels per acre. Reported yields ranged from a low of 12.9 bushels per acre in 1933 to 32.2 bushels per acre in 1979. In most of these years yield departure from the trend has been less than 10 percent. In three years, 1938, 1939 and 1943, yield departures greater than 10 percent above the moving average occurred. Yield departures greater than 10 percent below this average occurred in 1936, 1947, 1953 and 1974.

Table 3 indicates the number of years associated with each two bushel increase in soybean trend yield. Since 1935 it has taken 4 to 9 years to achieve a two bushel increase in yield. Over this time there is little evidence of any long-run change in the rate of increase. It should be recognized, however, that the record yield of 32.2 bushels in 1979 was 2.6 bushels higher than the previous record set only in 1977. Although 12 yield records have been broken since 1940, before 1979 the records were not broken by more than 1.3 bushels per acre.

Table 3. Number of years in U.S. soybean yield trend associated with each two bushel increase in U.S. soybean yield, 1935 to 1975

Change in trend yield ^{1/} (bushels/acre)	Inclusive years	Number of years
16.0-17.9	1935-1938	4
18.0-19.9	1939-1947	9
20.0-21.9	1948-1956	9
22.0-23.9	1957-1961	5
24.0-25.9	1962-1968	7
26.0-27.9	1969-1975	7

Source: Reference no. 77.

^{1/} Trend yield is measured as a nine year moving average from 1931 to 1980.

Regional Trends

For this report three major soybean producing regions are examined. These include the Corn Belt, Delta and Southeast. Figure 5 delineates the three major production areas and indicates the 1978 to 1980 mean percent of national production for each state. These three regions, (Corn Belt, Delta, and Southeast) accounted for 82 percent of the national production.

Early soybean production was primarily confined to the Corn Belt region. In 1945, these five states produced all but 13 percent of the soybeans grown in the U.S. Since 1945, however, production has significantly expanded to southern states. Production in the three Delta states of Arkansas, Mississippi, and Louisiana averaged 14 percent of national production over the 1978-1980 period. Similarly, because of increases since 1945 in the six southeast states, this region accounted for 13 percent of the national production during

Figure 4. U. S. soybean yield trend, 1930 to 1980.

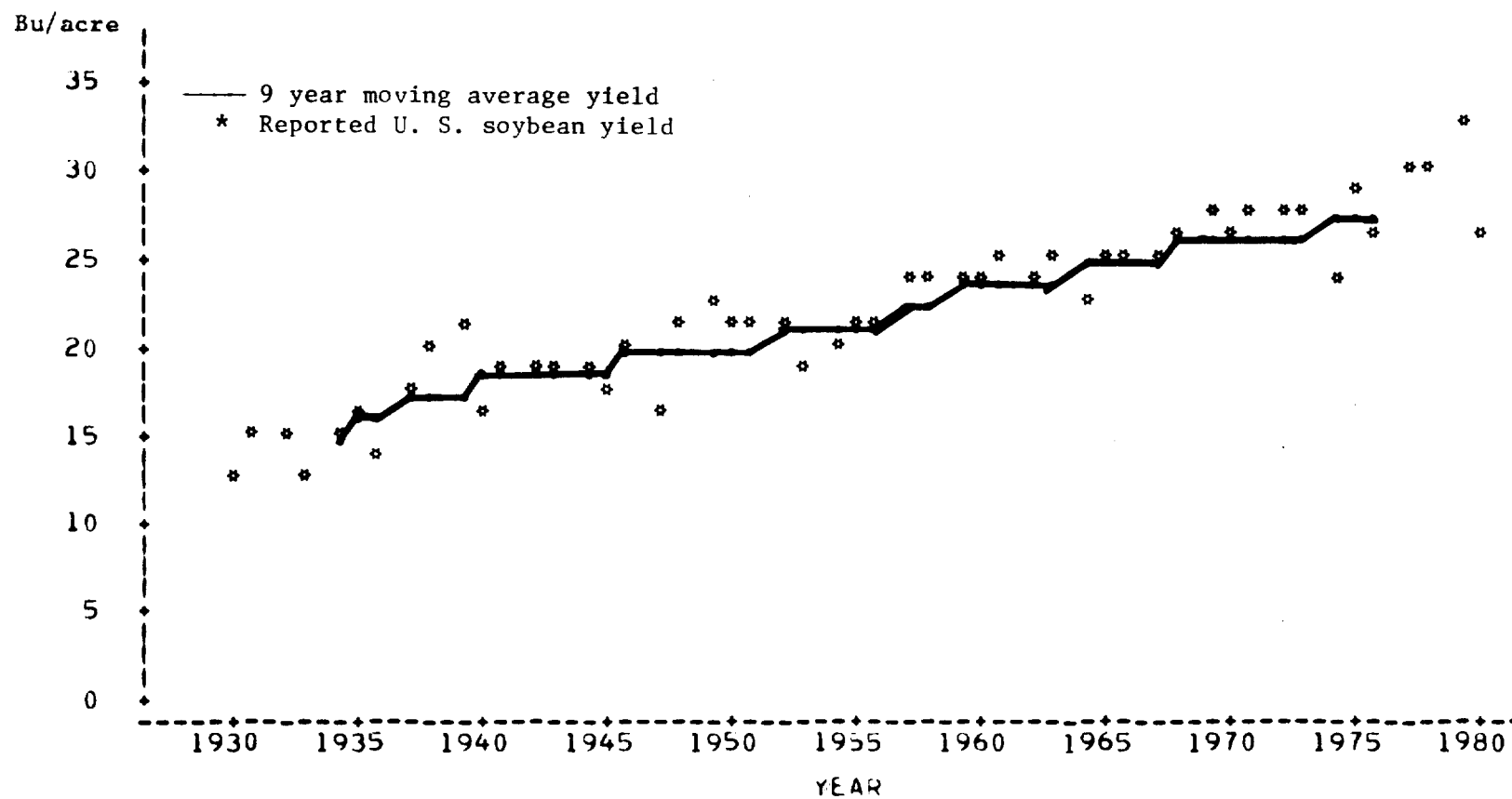
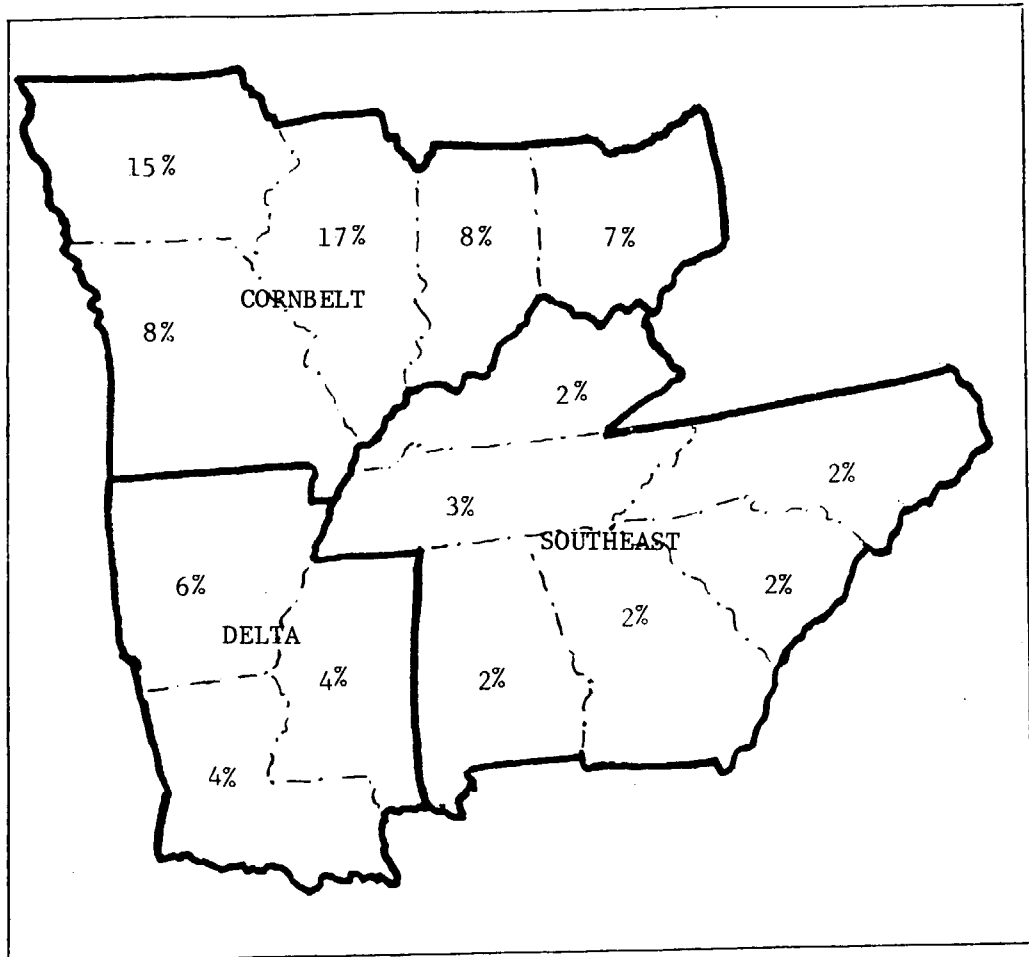


Figure 5. Major U. S. soybean producing regions and mean percent of national production by state, 1978-1980.



the period. For this report the Southeast soybean producing region includes North Carolina, South Carolina, Georgia, Alabama, Tennessee and Kentucky. Production in the Corn Belt averaged 55 percent of the national total for the three year period.

Soybean acreage increased over the last thirty years by 21.4 million acres in the Corn Belt, 10.6 million acres in the Delta and 11.2 million acres in the Southeast. This acreage change in the Southeast represents an eleven-fold increase. For the Delta region the change is a six-fold increase, and for the Corn Belt acreage more than doubled over this time. In all of the Southeast and Delta states, soybean acreage is now the largest of all field crops. In the Corn Belt, soybean acreage is only exceeded by corn, and in Missouri soybean acreage exceeds corn acreage.

To allow for such increases in soybean acreage, substantial shifts in land use and cropping systems were necessary. This shift included reductions in the planted acreages of other crops, clearing of forest land, conversion of pasture and the use of idle land previously used for conservation or under commodity price support programs [61]. Associated with these land use shifts are potential impacts on yields.

Trends in yields since 1944 for the three soybean production regions are plotted in Figure 6. Soybean yield trends are upward in all regions, but the yield levels are quite different between regions. Corn Belt yields have been consistently higher than either the Delta or Southeast Region's yields. Over the last thirty years Corn Belt yields have averaged over six bushels per acre higher or approximately 25 percent more than the yields in the southern regions. In the last fifteen years this yield difference has widened to approximately 7.5 bushels per acre.

As indicated in Table 4, there is little difference in soybean yield variability between regions, but there has been a reduction in yield variability in recent years in all regions. In all states except Ohio variability as measured by the coefficient of variation was lower in the later time period. The reduction in yield variability is most notable in the southern states where the coefficient of variation is reduced by approximately one-half.

DEFINING TECHNOLOGY AS A COMPONENT OF AN AGGREGATE CROP YIELD MODEL

The technology component as used in aggregate crop yield models in the past has been broadly defined. Many yield model researchers have grouped factors impacting on yields into three categories: weather, soils, and technology. Differences in soils have commonly been accounted for by fitting a model for a specific geographic area with the implicit assumption that within the region there is little year to year variation in the production capability of the soils on which a crop is grown. A trend variable, usually year, has been used to account for technology, with all remaining variation in yield to be explained by various weather variables. As a consequence, the technology component includes basically all factors, except weather and soils, which have impacted on crop yields over time. This component then must reflect the simultaneous effects from the development of new or improved production inputs and practices, year to year changes in the quantity or timeliness of all applied inputs and practices, and changes in land quality.

Figure 6. Soybean yield per harvested acre, Corn Belt, Delta and Southeast Regions 1945 to 1980.

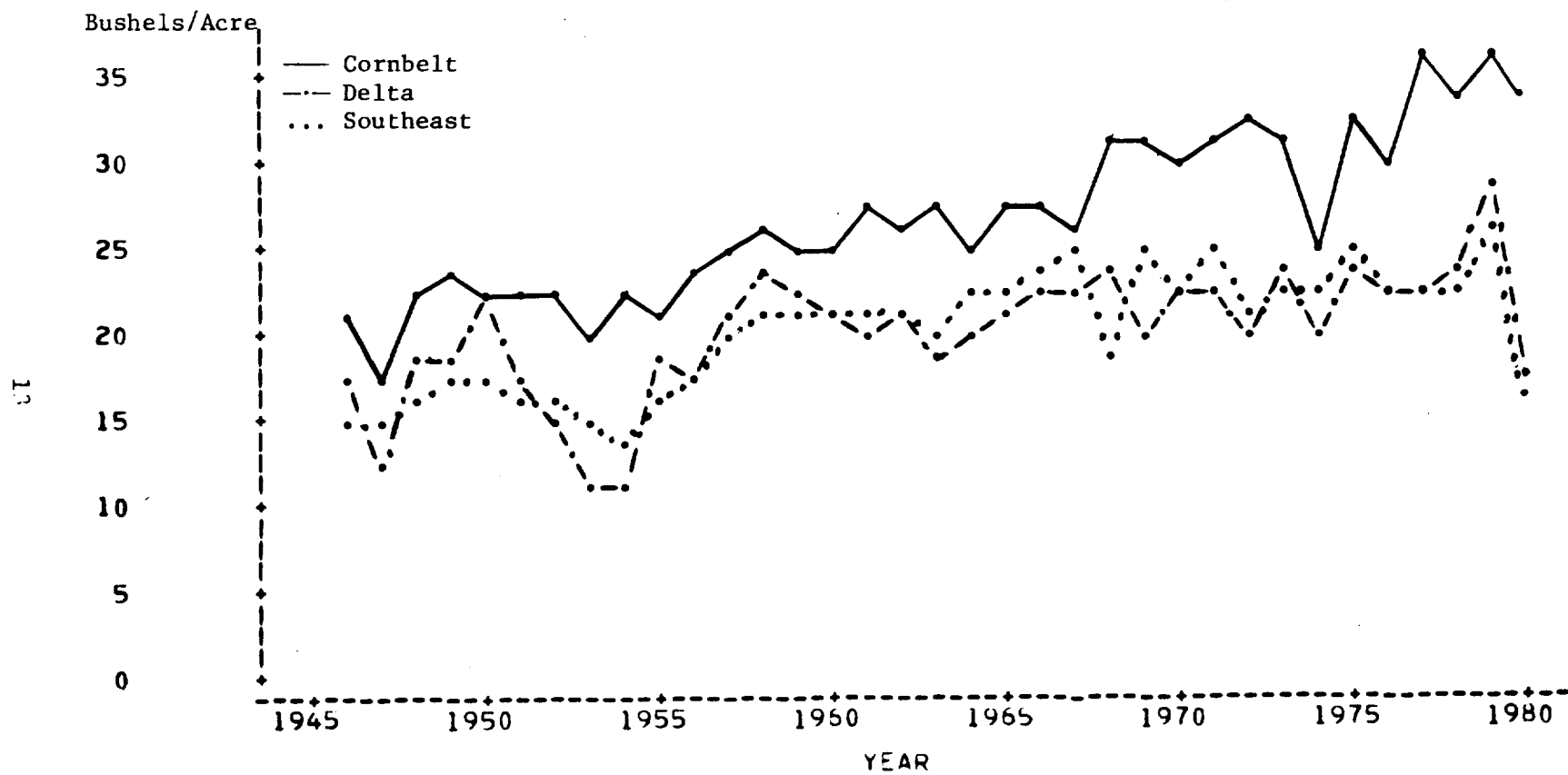


Table 4. Soybean yield variability in the Corn Belt, Delta and Southeast Regions, by the periods 1944-1964 and 1965-1979

	Standard Deviation		Coefficient of Variation	
	1944-64	1965-79	1944-64	1965-79
	- Bushels/Acre -		- - - Percent - - -	
Corn Belt	3.2	3.3	13.7	10.6
Ohio	3.0	4.1	13.2	13.8
Indiana	3.2	3.9	13.7	12.4
Illinois	3.1	3.7	12.7	11.5
Iowa	3.9	3.7	16.2	11.4
Missouri	4.9	3.3	25.7	12.7
Delta	3.6	2.5	20.0	10.8
Arkansas	3.6	2.4	19.7	10.6
Louisiana	4.0	2.2	22.0	9.1
Mississippi	4.3	5.1	24.8	21.7
Southeast	3.1	1.8	17.8	7.8
North Carolina	4.2	2.0	23.3	8.7
South Carolina	4.5	2.7	33.1	13.2
Georgia	3.8	3.8	30.8	17.1
Alabama	3.3	1.7	17.2	7.1
Tennessee	3.4	2.4	17.4	8.7
Kentucky	3.7	2.0	19.3	8.5

It would be nearly impossible to identify all factors which directly or indirectly influence crop yield. Crop yield is the result of a complex production system involving many interacting factors. In this section of the report a generalized systems approach is used to conceptualize a crop yield model, to identify general kinds of factors, and to apply theory as to how they potentially interact to influence aggregate yield. This conceptual framework will be used to define the technology components and identify major factors.

Such a conceptual model needs to address not only the physical-biological aspects of crop production but also the economic and institutional dimension. The physical-biological dimension includes the natural resources of soil and weather as well as the physical production inputs of seed, fertilizer, labor, farm machinery, fuels, etc. The economic dimension includes the role of prices in allocating the various factors and natural resources to a specific productive use. The institutional dimension includes various incentives, sanctions, regulations or other public policy measures put forth to achieve broad societal goals. These three interacting dimensions are seen as important potential forces producing year to year variation in crop yield.

What is important in assessing past as well as forecasting future yield impacts from technological change is a measure of that which is actually applied. This can be measured totally within a physical-biological dimension without regard to the effect of economic or institutional factors. However, to forecast the technology component one needs to account for the economic and institutional factors which impact on its future development and adoption. It is reasonably certain that applied technology in any year will fall short of the highest

yielding technology due to a lag in the acceptance of new technology or a lack of economic incentive. The rate of adoption is a dynamic process which can vary over time and between regions. The economic and institutional dimensions include those factors affecting technology development and adoption, which can result in negative or positive yield impacts.

Physical-Biological Dimensions

Von Liebig was among the first researchers to study the relationship between fertilizer or nutrient inputs and crop yield. He believed that crop yields were proportional to the amount of available nutrients and that yield would not be increased by the addition of one or more nutrients when they already are in sufficient supply. Liebig's "law of minimum" suggests that plants require nutrients in a given ratio and that yield varies directly with respect to the quantity of the nutrient available in the most limiting supply [31, 54]. When that nutrient is added, yields increase. The maximum yield achievable from additions of that nutrient is the point at which some other nutrient or factor becomes the most limiting. This suggests that yield increases only with the addition of the most limiting factor and that the addition of any other input will not influence yield.

Another important production concept is the law of diminishing returns. This law states that as equal increments of one input are added to a production process while some other inputs remain fixed, beyond some point the resulting increment of product will decrease [11]. In other words, with equal increments of a crop production input, yield increases will become smaller and smaller and eventually reach a maximum point. Further increases in yield can not be achieved unless there is an increase in the level of technology or a change occurs in the fixed inputs.

The relationship between physical-biological production inputs and crop yield perhaps can best be explained using the concepts of a production function. In theory, the production function can incorporate the concepts of the "law of diminishing returns" and the "law of minimum." Although production functions do not directly address weather and other risk factors, they can be included in a general model such as equation 1 [4].

$$(1) \quad Y = f(X_1 \dots X_g, X_{g+1} \dots X_h, X_{h+1} \dots X_n)$$

where:

Y = production per unit of land (yield)

X_1 to X_g are risk variables including weather, pest, disease, etc.

X_{g+1} to X_h are capital input variables.

X_{h+1} to X_n are all other physical factors influencing yield that are fixed in a production system.

Numerous risk variables can be identified which interact with soils and capital inputs to affect crop yield. Relevant monthly, weekly or even daily measures of precipitation, temperature, solar radiation or wind are among

the important risk variables. The variable, capital inputs include those resources available to the farmer which he may employ in various quantities in the production process. These variables include seeds, fertilizer, pesticides, tillage implements, fuels, and labor, which are identified and measured as to specific quantity, quality and timeliness. The remaining factors in the production function include all other physical or biological aspects of crop production including soils which are assumed to be fixed within the production period.

In such a physical model, technology is commonly defined as the functional relationship, (f) , identifying how factors interact to influence yield [47]. It defines what factors are used in fixed proportions and when each factor becomes limiting according to the "law of minimum." It also defines how one factor may substitute for another in the production process. Thus the function defines not only the input-output relationship but also the interactions among variable inputs. The production function is defined only for a specific point in time, thus implying certain fixed as well as variable factors, and a fixed state of available technology.

As one attempts to generalize across production systems and over time, factors previously assumed to be fixed become variable, the relationship between variables changes and new or improved factor inputs become available. Equation 2 is used to conceptualize such input-output relationships.

$$(2) \quad Y = f' (X_1 \dots X_g, X_{g+1} \dots X_h, X_{h+1} \dots X_n, t)$$

Where:

Y = production per aggregate unit of land (yield)

$X_1 \dots X_g$ are risk variables (weather, disease, pests, etc.)

$X_{g+1} \dots X_h$ are capital input variables. (These variables include the addition of new inputs)

$X_{h+1} \dots X_n$ are the previously assumed fixed factors, but which now can vary over time and in space (irrigation, soil depletion, and soil types are examples)

t = technology (a measure of available crop production technology).

Similar functions to equation 2 have been used to measure aggregate production relationships from cross section data, as well as technological change with time series data [4, 26]. Klein suggests that if there exists a production function for individual firms, there should also exist an aggregate function for all similar firms [45]. Technology has been separately identified from all other variables assumed to vary with time. Technology is always presumed to be positive since knowledge or information about a production process does not regress. Prices and institutional constraints, however, can cause positive, negative or neutral changes over time in the capital input variables.

Economic Dimension

The economic dimension to a crop yield model includes the role of prices and its impact on the quantity of capital inputs and quality of land employed in the physical-biological production function. Assuming the feasibility of estimating a physical-biological relationship and assuming a maximum profit goal of the producer, then prices become a determining factor as to the level of employed capital inputs. The optimum employment level for a specific factor is reached when the cost of an additional unit is equal to the value of the added output when employed. Under conditions of diminishing marginal productivity, a factor's optimum level of use is reached when the first partial derivative of equation 1 with respect to inputs X_{g+1}, \dots, X_h is equal to the price ratio of the particular input and product. Equilibrium use levels for all capital factors is reached when the ratio of the marginal product of a specific factor to its price is equal for all factors.^{3/}

Similarly then for the aggregate function, equation 2, there must also be a maximum profit equilibrium quantity of capital inputs determined by price. This equilibrium condition is stated in equation 3.

$$(3) \quad \partial Y / \partial X_i = P_{x_i} / P_y$$

for all X_i where:

X_i = Capital inputs X_{g+1} to X_h

P_{x_i} = Price of input X_i

P_y = Price of output Y

$\partial Y / \partial X_i$ = first partial derivative of equation 2 with respect to X_i .

This theory tells us that when the price ratio changes, stemming from any one input or the output, then one can anticipate adjustments in the quantity of inputs. When the ratio decreases, because of a decrease in the price of fertilizer, for example, it is anticipated that a larger quantity of fertilizer will be employed as it is substituted for other factors or because more can be purchased with a fixed capital outlay. If the ratio decreases, because of a commodity price increase, it is anticipated that larger quantities of all inputs will be employed at a new equilibrium point.

Besides price changes, another possible reason for a change in the equilibrium input quantities is when there is a technology breakthrough. Such a technological change enables farmers to produce more from the same quantity of inputs or to produce the same yield from a smaller quantity of inputs. For example, improved information about the proper timing and placement of fertilizer materials may increase crop yields without any change in the quantity

^{3/} Proof of profit maximization can be found in most micro economic textbooks such as reference no. 11.

applied. When such a technological change occurs, the ratio, $\partial Y / \partial X_i$, for any one or several capital inputs changes, and adjustments in the quantity of inputs occur to establish new equilibrium or maximum profit conditions of equation 3.

Another important group of variables, whose quantity is determined to a certain extent within an economics context, deal with the land base. In equation 2, inherent differences in soils as well as the quantity of natural resource developments were identified as potential factors influencing crop yield. Like the capital input factors, the choice of land quality to be used in the production of a crop is also determined within an economic context. The assessment of "land rents" associated with land quality can be used to indicate how prices and technological change can cause year to year changes in aggregate land quality.

"Land rent" is defined as that portion of total value of product which remains after payment is made for all other factors including normal profits to management [5]. Land is only brought into production when it can earn a rent, and even within a single farm context, its use will shift from one crop to another when there is opportunity to earn a higher rent. The high quality land which requires fewer inputs and has lower production costs earns a higher rent than land requiring more production inputs for a given crop. When a crop price is low, only the higher quality land can earn a rent, but as the crop price rises, it becomes profitable to bring lower and lower quality land into production. Similarly, lower input prices and new technology will cause lower quality or marginal land to come into production or to shift between crops.

Low quality land does not necessarily imply low crop yields. Often high development costs are incurred in order to bring new land into production. These may include the cost for land clearing, drainage or irrigation systems. Once these resource developments are in place, the crop yields may be as high or higher than on land earning a much higher economic rent. Low quality land, of course, may also be low yielding land. Such land, pasture for example, may not have a high cost associated with bringing it into production but with the same variable inputs has lower yields than land with high development costs. As a consequence, it earns a lower rent and it is brought into production only when commodity price is sufficiently high to cover all production costs.

Commodity price, the price of capital inputs, land development costs, and technological change can result in year to year, and especially long range, changes in the quantity of capital inputs and the quality of land used in production. Additional acres will come into production and influence yield with a higher commodity price, technological change, or lower capital input prices. Similarly, additional capital inputs or land developments will occur with these price changes or a technological change and have an impact on yield. It can be anticipated that price conditions leading to larger input quantities per acre will have a positive impact on yield but will reflect the law of diminishing marginal productivity. However, the yield from price changes or new technology causing substitution between production inputs or shifts in crop acres is less certain. If there is little development cost associated with bringing the new land into production, it can be

anticipated average yields will be lower and have a negative impact on aggregate yields. However, if substantial costs are associated with the marginal land (irrigation, for example), then the yields may be sufficiently high to have a positive effect on the aggregate yield. Changing prices or technological change may result in a substitution of one input for another. Often these substitutions result in cost or labor saving (reduced tillage systems, for example) and may have negative or positive influences on yield.

Institutional Dimension

The institutional dimension to a crop yield model addresses the non-market controls or incentives imposed on producers and consumers to achieve the long-run health, safety, aesthetic and general well-being goals of society. This dimension of the model basically considers the role of governments to equitably distribute profits and incomes and to control or direct the use of specific factor inputs. Within the context of a crop yield model, the institutional dimension includes the yield effect of farm income support and production stabilization programs, environmental and safety legislation, programs to protect and insure the long-run availability of natural resources, the public involvement leading to large area drainage and irrigation and the funds available for yield increasing research.

Farm income support and production stabilization programs have sought to increase and stabilize commodity prices. During periods of surplus production these programs sought to maintain certain price levels by restricting planted acreages and purchases of excess production. The programs removed certain risks of low income and enabled producers to obtain greater capital for the purchase of variable factor inputs or long range investments. The acreage restriction was limited to only one input, and it was possible to increase other inputs to enhance yields. Also, since most farms have a rather wide range of soils, the less productive soils were idled leaving the better soils for production. As a consequence these programs potentially influence aggregate yield through changes in land quality as well as the substitution of capital inputs for land.

Environmental and safety legislation may limit or ban the use of certain production inputs deemed to be detrimental to health and safety or may require the use of specialized equipment and licensed operators. Often when a pesticide is banned, substitute chemicals are not readily available or available only at higher cost. Additional labor, tillage and other inputs can partially substitute for the banned chemicals. As a result of such legislation, yields may be adversely influenced [14].

A number of federal and state programs have been initiated to increase land productivity through special development projects or to protect its long run productivity through soil conservation practices. Large group irrigation, drainage and flood protection projects which have been supported and subsidized by federal and state governments have potentially influenced aggregate yields. Also, subsidies for soil conservation practices have provided economic incentives for farmers to accept lower yields with the adoption of soil conserving practices.

A final important institutional element is the developmental research of public institutions and private industry leading to innovations. This includes new physical-biological inputs of improved seed varieties, chemicals or mechanization. It also includes new knowledge about management or plant growth processes which allows more timely or efficient use of the same combination of physical inputs. Double cropping and conservation tillage systems are examples of recent management strategies being employed that potentially influence yield.

PRODUCTION INPUTS AND CULTURAL PRACTICES INFLUENCING CORN AND SOYBEAN YIELDS

World War II brought about significant changes in agricultural production inputs. In response to labor shortages and needs for increased production, many labor saving and yield increasing inputs were developed and adopted. A better understanding of plant growth processes has continued to cause refinement of these inputs and the development of improved or new yield increasing inputs. Genetic improvements, pesticides and fertilizer have been identified as major factors contributing to increases in corn and soybean yields. In addition, mechanization has led to changes in the way crops are grown and harvested. Timeliness of planting, tillage systems and double cropping are cultural practices that have and continue to influence yield.

This section identifies adoption periods or use trends for important yield increasing inputs and practices. Included in this section are changes in the use of fertilizer and pesticides, improvements in corn hybrids and soybean varieties, changes in row spacing and plant population, tillage systems, and double cropping. Research results from site specific or experimental studies are used to provide an indication of the potential yield effect from the input or practices when adopted.

Fertilizer

Much of the past increase in agricultural yields has been associated with the increased use of commercial fertilizers. Since 1950 there has been a dramatic increase in the percentage of corn and soybean acreages fertilized and the pounds of nutrients applied per fertilized acre. In addition there have been improvements in the timing of application, placement in the soil and quality of fertilizer material leading to more efficient utilization of applied nutrients. Numerous studies have been made to ascertain plant nutrient needs and their response to applied commercial fertilizer. Recommended application rates have been developed considering alternative yield goals, existing soil nutrient content, plant population, cultural practices and other environmental conditions. This section of the report will discuss regional trends in commercial fertilizer use on corn and soybeans, as well as the crop nutrient needs, and recommended fertilization rates associated with various yield goals and alternative production practices.

Limited data are available prior to 1964 to illustrate state trends in specific nutrients applied to corn or soybeans. Regional estimates of the number of corn and soybean acres receiving commercial fertilizer and the nutrient application rates were made for 1947 and 1950 [81]. In 1954 and 1959 state level estimates were made [82] and beginning in 1964 annual state estimates were made for most of the major corn and soybean producing states [78].

Corn

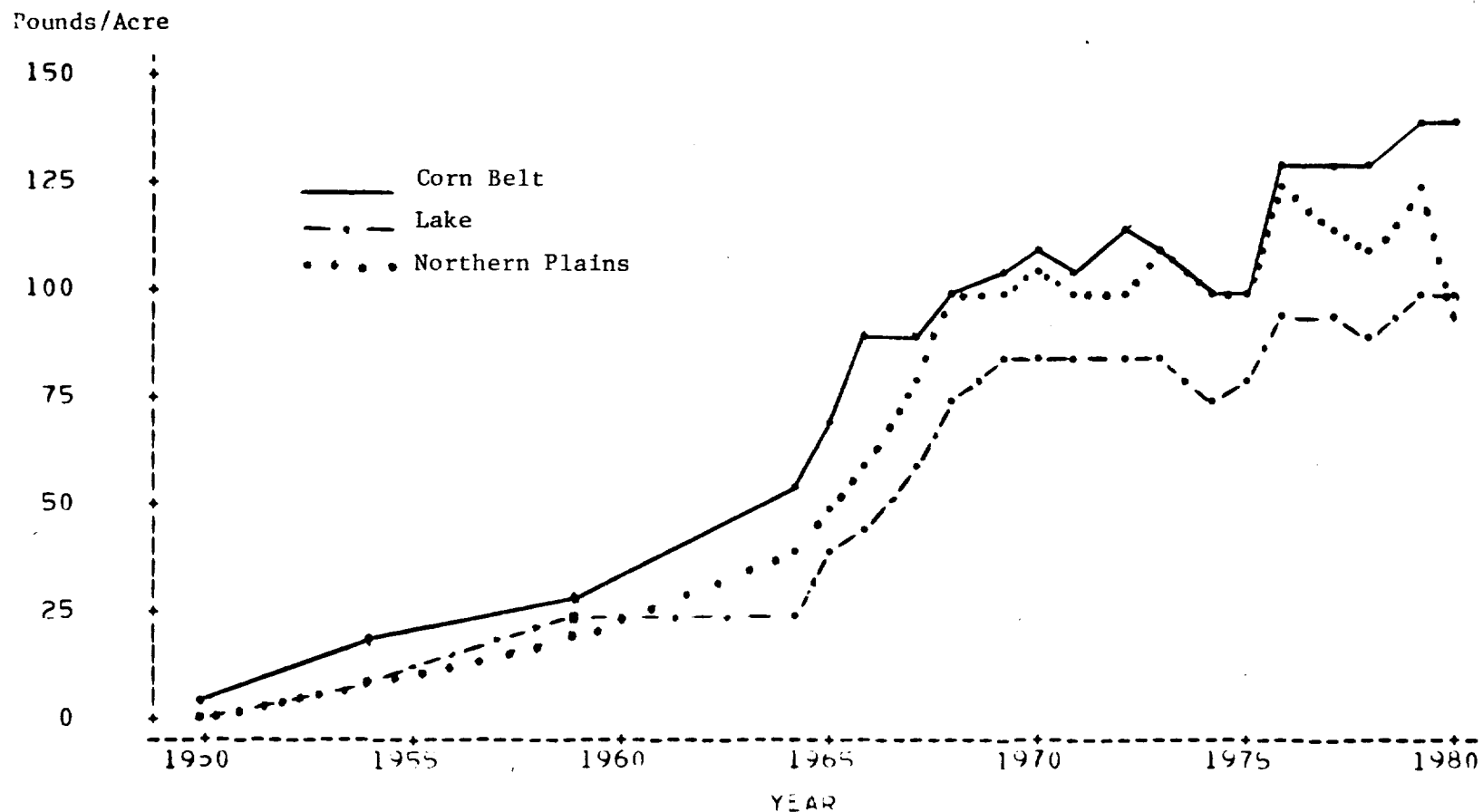
Providing for the nutrient needs of corn is not only a necessary condition for obtaining high yields but has become a major management concern for profitable production. Nitrogen, phosphoric acid and potash are three principle plant nutrients applied to corn. Although the general trend in application rates per harvested acre has been upward for all three nutrients, differences occur among nutrients as well as production areas. Some of these differences are explained by nutrient needs of the plant, inherent fertility levels of the soil, weather, changing cropping practices and prices.

Nitrogen. Nitrogen is the plant nutrient most highly associated with corn production and corn yields. The increased use of nitrogen fertilizer on corn since 1950 is illustrated in Figure 7 for the Corn Belt, Lake and Northern Plains Regions. The trends follow a similar pattern in all three regions. From 1950 to 1964, the use of nitrogen fertilizer became an established practice and the number of pounds per harvested acre increased from minimal levels to over 50 in the Corn Belt, 26 in the Lake and 38 in the Northern Plains. This was followed by an even greater increase during the late 1960's when the application rates across the entire corn producing regions increased 50 to 80 pounds per acre. From 1970 to 1975 there was little change in application rates and declines occurred in some years. This was followed, however, by another short but significant increase at the end of the 1970's.

Prior to 1950 the use of commercial nitrogen fertilizer was not widespread. Many farmers relied on manure and the use of legume crops in rotation with corn to provide plant nutrients. In 1950, over half of the harvested corn acres in the Corn Belt and Lake regions received no nitrogen fertilizer and on the fertilized land the application rates averaged only 8 pounds in the Corn Belt and 3 pounds in the Lake region. In the Northern Plains, the application rate was estimated to be 22 pounds per treated acre but only 8 percent of the acreage was treated.

The period from 1950 to 1964 is characterized by widespread adoption of nitrogen fertilizer and increased application rates. During this time the knowledge of the yield response and growth of the nitrogen fertilizer industry led to higher adoption and use rates. Widespread adoption occurred first in the eastern corn producing states and later moved into the western states. In 1954, it was estimated that over 90 percent of the corn acreage in Ohio and Indiana and 80 percent in Michigan and Wisconsin received commercial fertilizer. It was not until the mid 1960's, however, that at least 90 percent of the corn acreage in Illinois, Iowa, Missouri, Minnesota, Nebraska and Kansas received nitrogen fertilizer. In South Dakota the adoption of nitrogen fertilizer lagged other states and even through the 1970's 35 percent or more of the corn acreage received no commercial nitrogen fertilizer.

Figure 7. Pounds per acre of nitrogen fertilizers applied to corn, Corn Belt, Lake and Northern Plains Regions, 1950 to 1980.^{1/}



^{1/}The rate of applied nitrogen fertilizer was calculated as the product of the proportion of acres receiving the nutrient and the pounds of available nutrient applied per receiving acre.

Source: The data for 1950, 1954 and 1959 are reported in reference nos. 81 and 82. The data for 1964 to 1980 are reported in reference nos. 78 and 80.

Simultaneous with the increase in fertilized acreage were increases in the pounds applied per acre. From 1950 to 1964 the average amount applied increased 54 pounds in the Corn Belt and 47 pounds in the Northern Plains, while in the Lakes Region the increase was only 28 pounds per acre. The applied nitrogen in the Lake Region has remained 20 to 40 pounds per acre lower than in the other regions as illustrated in Figure 7.

During the late 1960's there was a rapid growth in the fertilizer industry and particularly in the capacity to produce anhydrous ammonia, a dominant form of nitrogen fertilizer. The introduction of technologically advanced manufacturing plant design in the early 1960's capable of producing anhydrous ammonia at reduced cost resulted in a rapid expansion in nitrogen production and falling prices. From 1964 to 1969, the production capacity for anhydrous ammonia increased 1.7 times [60], and the price fell from \$126.00 per ton to \$75.00 per ton [83]. During this short time span, the nitrogen application rates on corn increased two to three times.

By 1970, additions to the fertilizer industry's production capacity had stopped. Also at this time declining world food supplies led to an increased export demand for fertilizer and the release of set aside acres for domestic production. This eliminated the excess fertilizer production capacity and an upward pressure on price began to develop. Late in 1971, price controls were put in effect and remained until late 1973. Minor fertilizer shortages resulted in some areas as a result of the price controls and generally there was little increase in the application rates of nitrogen from 1970 through 1973.

In 1974, after fertilizer price controls were lifted, the price of anhydrous ammonia more than doubled. The price peaked in 1975, reaching an average of \$265 per ton, which was a 300 percent increase within two years. Although the price of corn also increased substantially, reductions in fertilizer application rates accompanied this dramatic price spurt. As illustrated in Figure 7, the average nitrogen application rate in 1974 fell 9.5 pounds in the Cornbelt, 13.6 pounds in the Lakes and 6.5 pounds in the Northern Plains regions. Application rates continued at the lower levels in 1975, but a 25 percent price reduction in 1976 resulted in much higher rates that year. Prices continued to fall slightly through 1979 but took another upturn in 1980. The period from 1976 to 1980 had rather wide fluctuations in application rates with no definite directional trend.

The yield response from nitrogen fertilizer has been studied on a broad range of soils, cultural practices, cropping systems and weather conditions. Most cooperative extension services provide recommended fertilization rates associated with a yield goal. An integral part in developing these recommendations and estimating the yield response is the existing available nutrient in the soil. The recommendations are intended to sufficiently provide for the plant nutrient needs after taking into account existing soil nutrients and potential gains or losses to the soil nutrient pool.

A bushel of corn contains approximately .77 pounds of nitrogen [95]. The amount of nitrogen necessary to produce a bushel of grain, however, is somewhat higher and varies with yield. The yield response attributed to added

nitrogen exhibits diminishing returns, i.e., the response from each additional increment of available soil nitrogen is less than from the preceding increment. Corn yields of 75 bushels per acre are reported to remove about 78 pounds of nitrogen while yields of 150 bushels remove 198 pounds of nitrogen [38].

Potential additions to the soil nitrogen pool, other than commercial fertilizer, include mineralization of soil organic matter, release from preceding legume crops, livestock manure, and nitrogen released during thunderstorms. A preceding legume crop can provide 140 pounds of nitrogen per acre the first year and 30 pounds the second year [38]. Mineralization of organic matter in soils releases 1 to 2 percent of its total nitrogen annually. The amount of nitrogen released annually from mineralization is more a function of temperature than precipitation; consequently, the release rate is slightly higher in the southern Corn Belt than in growing areas further north [96]. The nitrogen content within the plow layer of mineral soils in the Corn Belt may contain from 500 to 5000 pounds of nitrogen per acre, but nearly all is in an unavailable form for plants to use. The nitrogen content and release from manure vary considerably depending on its source, handling techniques and moisture content. The amount of nitrogen released during thunderstorm activity that enters the soil is relatively small. In Illinois it is estimated to be 5 to 13 pounds per acre annually [95].

A major concern in developing nitrogen fertilizer recommendations is the nutrient loss associated with the specific soil, fertilizer material, tillage and management practices and anticipated weather. Besides crop removal the three major ways nitrogen is lost is by leaching, volatilization, and fixation [62]. Because nitrogen fertilizer dissolves easily in water, it readily moves downward through the soil and may be carried beyond the root zone and even into groundwater. Such loss is generally negligible in semi-arid regions, but it can be significant on irrigated land, sandy soils and areas of high precipitation. To prevent leaching on irrigated sandy soils, the Nebraska irrigation guide suggests that nitrogen be applied several times during the season and that up to one-third of the nutrient be applied with the irrigation water [63]. Studies in Champaign, Illinois found that 10.8 pounds per acre of nitrogen leached into drainage water during a year with normal rainfall, but in a high rainfall year the rate was 21.9 pounds per acre [95]. Greater loss from leaching occurs on sandy soils than clay soils and fall application of nitrogen is not recommended for sandy soils. Under certain conditions nitrogen may be lost through volatilization following application of anhydrous ammonia or surface broadcast on a dry soil. Most volatilization losses can be controlled by proper placement and timing of anhydrous ammonia application and the immediate incorporation into the soil of broadcast fertilizer. Losses from fixation occur when micro-organisms in the soil temporarily tie-up soluble nitrogen or when nitrogen becomes permanently afixed to the soil's clay structure. Nitrogen temporarily tied up by micro-organisms returns to the soil generally within the growing season depending on the amount of and type of residue returned to the soil and soil moisture conditions. Laboratory studies indicate considerable nitrogen may be held temporarily in this manner but that it has no serious effect on the available nitrogen pool.

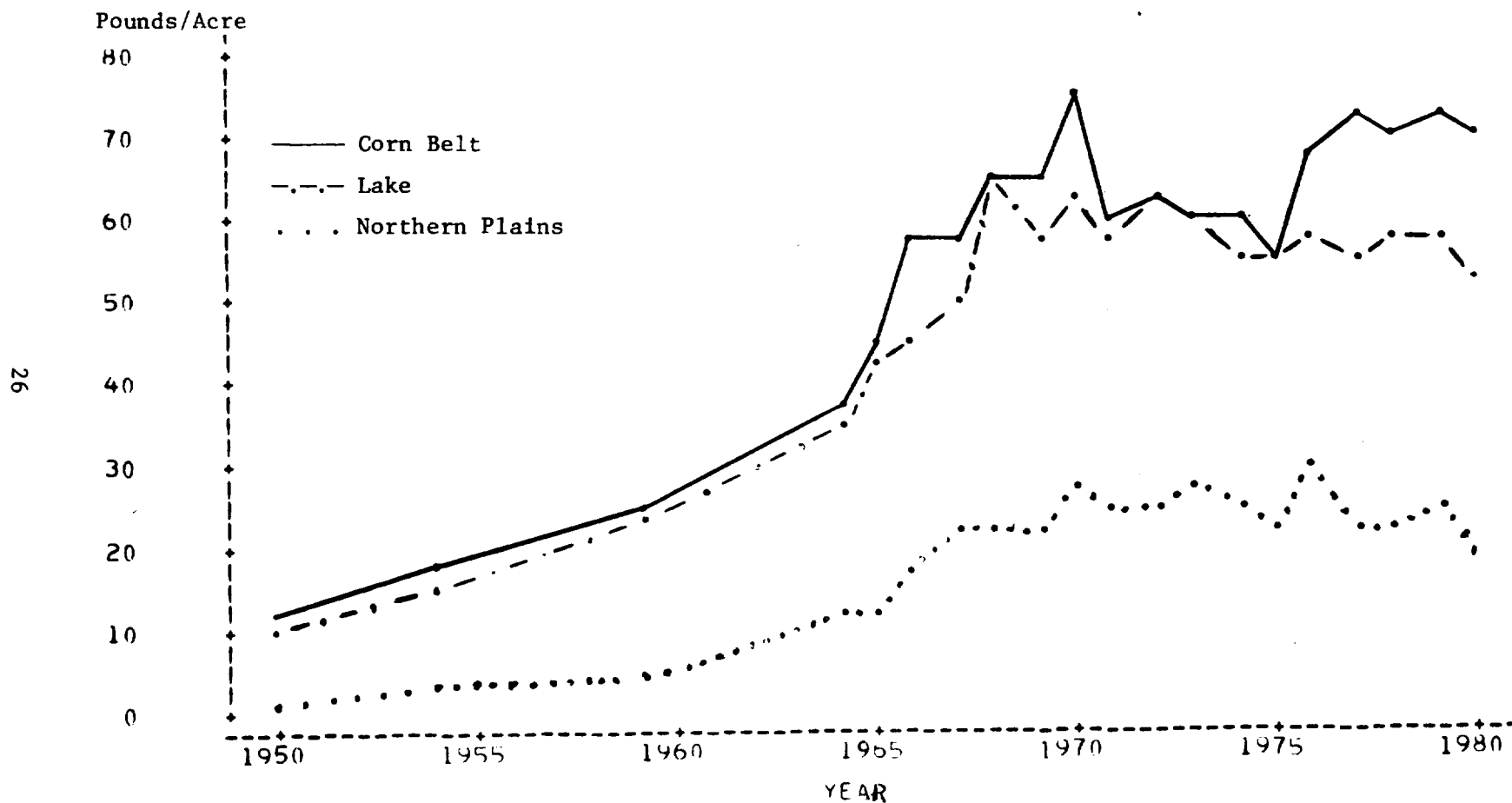
Phosphorus. The phosphorus application rates from 1950 to 1970 are illustrated in Figure 8 for the Corn Belt, Lake and Northern Plains regions. Between 1950 to 1970 there was a substantial increase in the amount of applied phosphorus fertilizer in all three regions. Following 1970 there has been no definite directional trend in any region, although there have been wide year-to-year fluctuations. The application rates of phosphorus in the Corn Belt and Lake Regions are quite similar; however, the rates in the Northern Plains are substantially lower.

The increased adoption and use of phosphorus fertilizer followed a similar pattern to that of nitrogen with substantial increases in adoption and application rates from 1950 to 1970. In the Corn Belt and Lake Regions the percentage of corn acres receiving phosphorus fertilizer increased from less than 50 percent in 1950 to generally over 90 percent following 1970. In the Northern Plains the increase was from approximately 30 percent in 1950 to over 50 percent in 1970. No significant change in the percent of acres receiving phosphorus fertilizer occurred during the 1970's. The application rates per acre increased during the 1950 to 1970 period but had no upward trend during the 1970's. The rate per harvested acre in the Corn Belt increased from around 12 pounds in 1950 to 35 pounds in 1964 and to 75 pounds in 1970. The increase was just slightly less in the Lake Region. In the Northern Plains Region where substantially less phosphorus is applied, the rate of increase was most significant in the late 1960's when the application rate increased from 11 pounds per acre in 1964 to 28 pounds per acre in 1970.

Unlike the price of nitrogen, the price of phosphate fertilizers remained relatively stable during the adoption and increased use period. From 1950 to 1967 the price of 45 percent super phosphate, a dominant form of phosphorus fertilizer, increased from \$67.10 to \$84.10 per ton [83]. The price fell slightly over the next three years but began to rise in 1970. With the removal of price controls in late 1973, the price jumped from \$87.50 in 1973 to \$150 per ton in 1974, then peaked in 1975 at \$214 per ton. In 1977 the price had fallen to \$148 but another sharp increase occurred in late 1979 and 1980 raising the May 1980 price quotation to \$251 per ton. Corresponding to these price fluctuations were some changes in application rates. A 4 to 7 pound per acre reduction occurred following the 1974-75 price jump. The rates generally returned to earlier levels prior to 1980 but fell again in 1980.

The corn yield response to phosphorus fertilizer has been widely researched and recommended application rates associated with yield goals are made by taking into account existing phosphate level determined from soil tests, soil type, pH and certain management practices. Unlike nitrogen, phosphorus is relatively immobile in the soils and losses are less affected by precipitation. Both acidic and highly alkaline soils, however, can result in added phosphorus fertilizer becoming insoluble and unavailable to plants. A soil pH range of 5.5 to 7.0 is generally suggested as being the most favorable for plant availability and minimizing its fixation in the soil [58]. Placement in the soil and tillage practices may also affect its availability to plants. Broadcast application along with tillage practices which do not include moldboard plowing result in an accumulation of phosphates near the surface [8].

Figure 8. Pounds per acre of phosphorus fertilizers applied to corn, Corn Belt, Lake and Northern Plains Regions, 1950 to 1980^{1/}.



^{1/} The applied rate of phosphorus fertilizer was calculated as the product of the proportion of acres receiving the nutrient and the pounds of available nutrient applied per receiving acre.

Source: The data for 1950, 1954 and 1959 are reported in reference nos. 81 and 82. The data for 1964 to 1980 are reported in reference nos. 78 and 80.

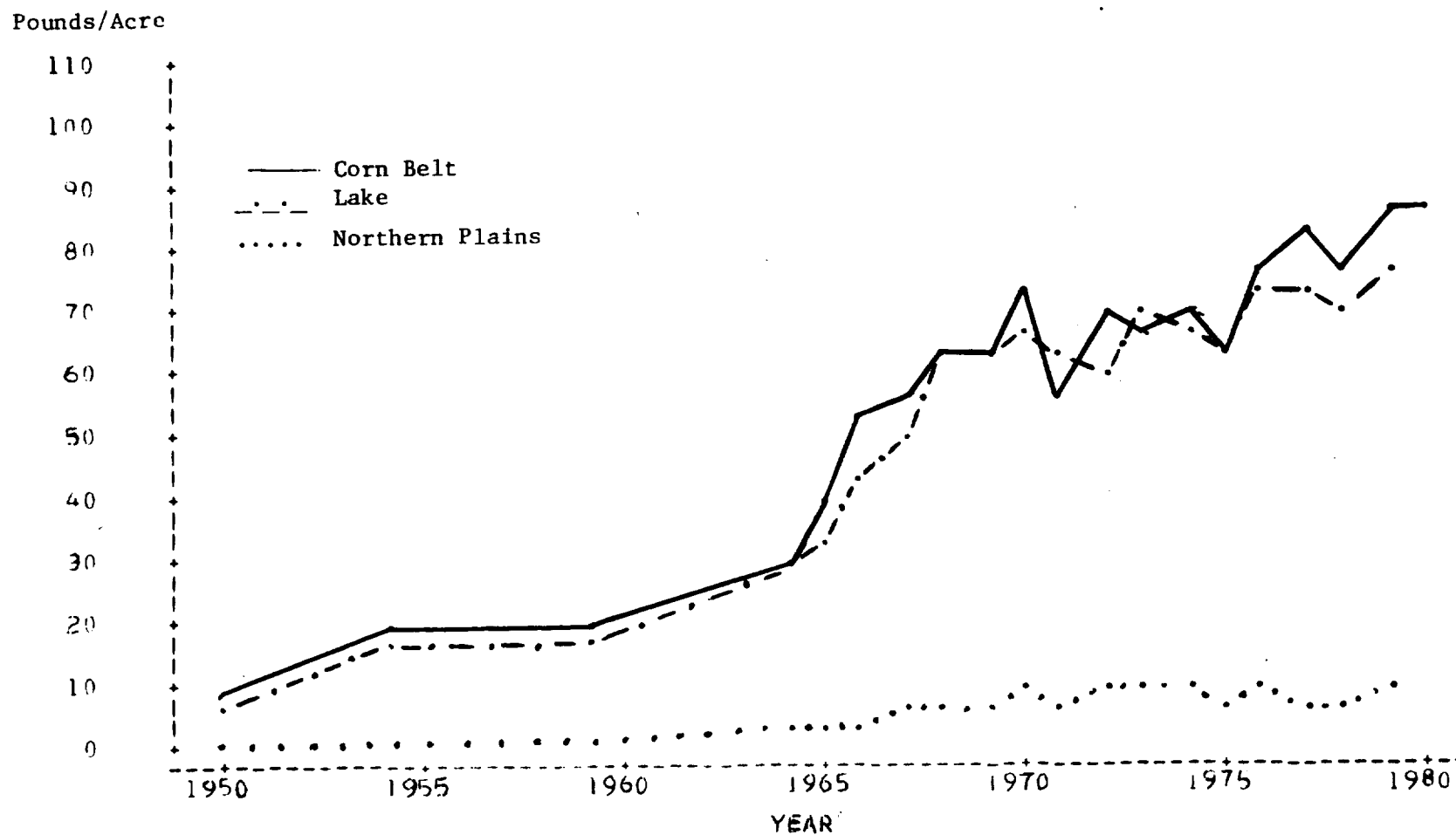
After obtaining proper pH levels in the soil, recommended phosphate applications generally include initial applications to achieve a medium or high test level and then maintenance levels associated with crop removals. A bushel of corn removes approximately .37 pounds of phosphate and apparently the amount does not vary significantly according to yield levels [38]. In years when yield goals are not achieved, carry-over phosphates may exist and can be credited to the next year's crop in maintaining the nutrient level. The yield response to phosphorus fertilizer in soils testing low in phosphate and with high nitrogen applications is significant. However, once medium to high levels are built-up in the soil, high yields can be maintained for a few years without additional phosphate fertilizer. Phosphate fertilizer recommendations are thus generally viewed as a build-up and maintenance program. As higher yields are obtained with improved hybrids and higher nitrogen application, addition of phosphates is needed to maintain the pool.

Potassium. Potassium application rates per harvested acre for corn are illustrated in Figure 9. Since 1950, increases of 70 to 80 pounds per acre occurred in the Corn Belt and Lake Regions, while application rates in the Northern Plains have generally been less than 10 pounds per harvested acre. The changes in rates in the Cornbelt and Lake Regions follow a similar pattern to the other nutrients with the largest increase occurring in the 1960's. In 1950, the application rates were only 8 and 6 pounds per acre in the Corn Belt and Lakes Regions, respectively. In the next twenty years the rates increased to 75 and 62 pounds, respectively in the two regions. In 1971 the rates fell slightly and remained at somewhat lower levels throughout the decade.

The price of potassium fertilizer declined slightly during the 1950's and most of the 1960's. Muriate potash cost \$57.20 per ton in 1950, but with increasing competition from Canadian potash exports, the price continued to fall to a low of \$47.80 in 1969 [83]. Following 1970, cutbacks in Canadian potash production and increased world demand caused some modest price increases through 1973. With the removal of price controls in late 1973, the price jumped some 60 percent in the next two years. Like the price of other fertilizer materials, its price fell slightly in 1976, but continued an upward trend through 1980. The May 1980 U.S. price of potash was \$135.00 per ton, nearly 2.5 times the price ten years earlier.

Although most soils contain large quantities of potassium, all but one or two percent is in mineral form and essentially unavailable for plants. That which is available varies widely between soils and geographic areas. Some soils and geographic areas have inherently higher levels of available potassium than others due to the mineral content of the parent material and degree of weathering. Generally the higher levels exist in more arid regions but differences also occur within humid regions. For example, in Illinois the northern two-thirds of the state has higher levels of available potassium than the Southern portion due to parent material differences [92]. Except for the extreme eastern counties, South Dakota soils are considered high in available potassium [94]. Soil pH also affects the availability of potassium and the equilibrium between unavailable and available potassium [58]. Certain clay structures and alkaline conditions can result in fixation of applied potassium fertilizer.

Figure 9. Pounds per acre of potassium fertilizers applied to corn, Corn Belt, Lake and Northern Plains Regions, 1950 to 1980^{1/}



^{1/}The rate of applied potassium fertilizer was calculated as the product of the proportion of acres receiving the nutrient and pounds of available nutrient applied per receiving acres.

Source: The data for 1950, 1954 and 1959 are reported in reference nos. 81 and 82. The data for 1964 to 1980 are reported in references nos. 78 and 80.

Like the other nutrients, corn yield response to potassium fertilizer varies with a number of environmental and management conditions in addition to existing nutrient availability. Based on soil tests to determine the existing nutrient level, potassium recommendations are generally to build up the soil nutrient pool to a medium or high level, then apply maintenance levels to account for that expected to be removed by the crop. Corn removes approximately .24 pounds of potassium per bushel harvested [58]. When corn is harvested as silage or the plant residue is removed, much higher application rates are necessary for maintenance.

Yield response to added potassium fertilizer can be influenced by tillage systems and fertilizer placement. Poor aeration in the soil reduces the uptake of potassium more than it does other nutrients. Also potassium is relatively immobile in the soil and must be placed where it will be available to plant roots. Row application is frequently more efficient than broadcast, especially when low rates are applied and the broadcast fertilizer is not plowed down [38]. Broadcast applications with minimum tillage have resulted in an accumulation of potassium within the top five inches of soil. Studies in Minnesota found decreased potassium content in corn leaves with broadcast application and a no-till production system [6 and 7]. Moldboard tillage, along with providing better fertilizer distribution, also increases soil aeration for better utilization of applied potassium. Under no-till systems, some extension specialists [23, 6, 7] recommend a higher fertilization rate and moldboard plowing every three or four years.

Soybeans

Relative to corn, soybeans are considered to have a poor response to applied fertilizers. Although highest yields are obtained from highly fertile soils, consistent yield responses are generally restricted to soils testing very low or low in potassium and phosphorus [36, 39]. Soybeans have little response to nitrogen fertilizer [95]. Agronomists often state that soybeans respond to fertility, not fertilizer. Because soybeans are often grown in rotation with crops having a much better fertilizer response, they benefit from the carry-over nutrients. Agronomists often recommend applying added levels of phosphorus and potassium to the alternate crop in rotation because soybeans may benefit as much from the carry-over as from direct applications [73]. As a consequence, the trends of direct application of fertilizer to soybeans may not indicate the total impact of fertilizer on soybean yields.

Because soybeans are a relatively new crop to some areas of the Southeast and Delta, annual fertilizer data published by USDA since 1964 are not available for all states. In the Delta, state fertilizer estimates for Louisiana were not made until 1967. In the Southeast, fertilizer estimates were begun in 1966 for North Carolina, South Carolina and Tennessee but estimates for Georgia, Alabama and Kentucky did not begin until 1977. Consequently, the trend data in Figures 10 to 12 on pounds of nutrient applied per harvested acres between 1964 and 1977 reflect only those states where estimates were made. The data prior to 1964 is from the Agricultural Census and reflects estimates for all states within the region for the census years of 1954 and 1959 [81, 82].

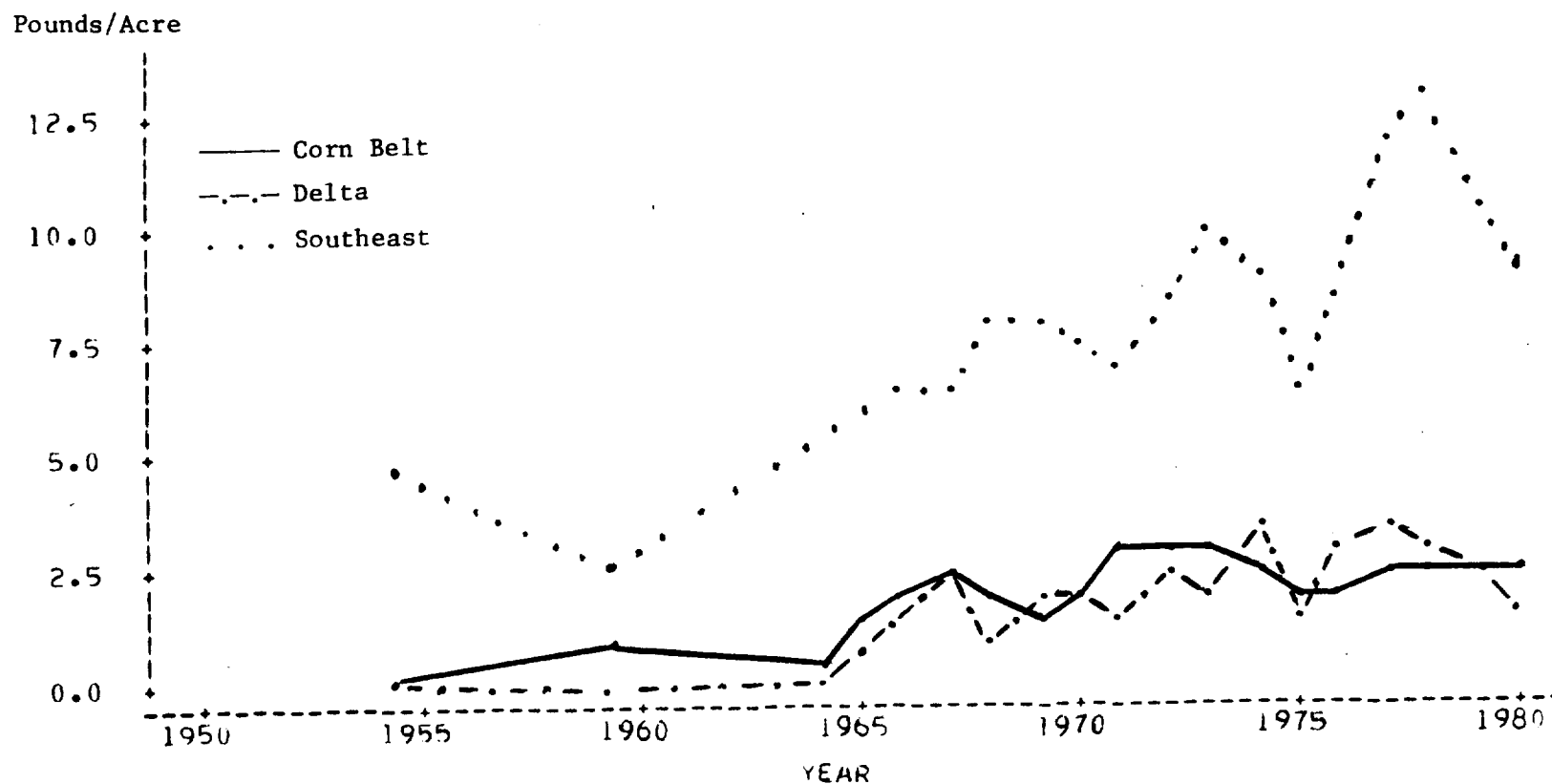
Nitrogen. Although nitrogen fertilizer is not highly associated with soybean yields, a number of farmers do apply small quantities. Figure 10 illustrates changes in average application rates per harvested acre in the three regions from 1954 to 1980. In the Corn Belt and Delta Regions, nitrogen application rates per harvested acre have been generally less than five pounds per acre. Although somewhat higher rates are applied in the Southeast, the rates have been less than ten pounds in most years. The higher rates in the Southeast result from an increased percentage of acres being fertilized. In the Southeast Region one-half or more of the soybean acreage receives nitrogen fertilizer while approximately one-third is fertilized with nitrogen in the Delta Region. In recent years in the Corn Belt, the proportion of soybean acreage receiving nitrogen fertilizer ranges from one-half in Indiana and Ohio to approximately one-fifth in the remaining states.

Because soybeans are a legume, bacteria on their root nodules can fix atmospheric nitrogen and, at least partially, provide for the plant's nitrogen need. A soybean yield of 50 bushels per acre accumulates some 250 pounds of nitrogen in the above ground material of which about 75 percent is removed in the grain [95]. When properly inoculated, nitrogen fixation by the plant supplies 30 to 60 percent of this total need. Under soil nitrogen stress conditions it may provide for even more of the need. Conversely, however, when high levels of soluble nitrogen are readily available in the soil, it will absorb the soluble nitrogen and fixation will account for a smaller proportion of the total plant needs. High levels of soluble nitrogen during early growth stages have been shown to retard nodule development necessary to provide the major nitrogen needs during the last growth stages. Research has shown little yield response to applied nitrogen fertilizer, even when high rates intended to provide for the total nitrogen need are supplied [95].

Phosphorus. Unlike nitrogen, soybeans require phosphorus to be in an available form in the soil for adsorption and consequently commercial fertilizer is generally needed to replenish that removed by prior crops. Figure 11 indicates the application rates of phosphorus in the three major soybean regions. Again the high rates occur in the Southeast where a larger percent of the total soybean acreage is fertilized. Only a slight upward trend in use rate exists. Rates generally increased from 1964 to 1971 and again following 1976. The rate increase, however, over the entire period since 1964 has been no more than 10 pounds per acre in any of the three regions.

Consistent positive yield response from applied phosphorus fertilizer has been restricted to soils testing very low or low in available phosphorus [15 and 39]. The primary source of loss occurs with crop removal and soil erosion. Consequently, fertilization recommendations are first to apply necessary amounts to build up the nutrient to an optimal level and then make applications necessary to maintain that level based on crop removal. The build-up application differs widely among soils due to past fertilization and cropping practices, and the inherent phosphorus supplying capability of the soil. The inherent phosphorus supplying capability can vary significantly within a state. For example, in Illinois three regions are identified according to phosphorus supplying capability [90]. The build-up applications are considerably reduced in the high supplying areas and even the recommended maintenance levels may be less if soil tests are sufficiently high. In general

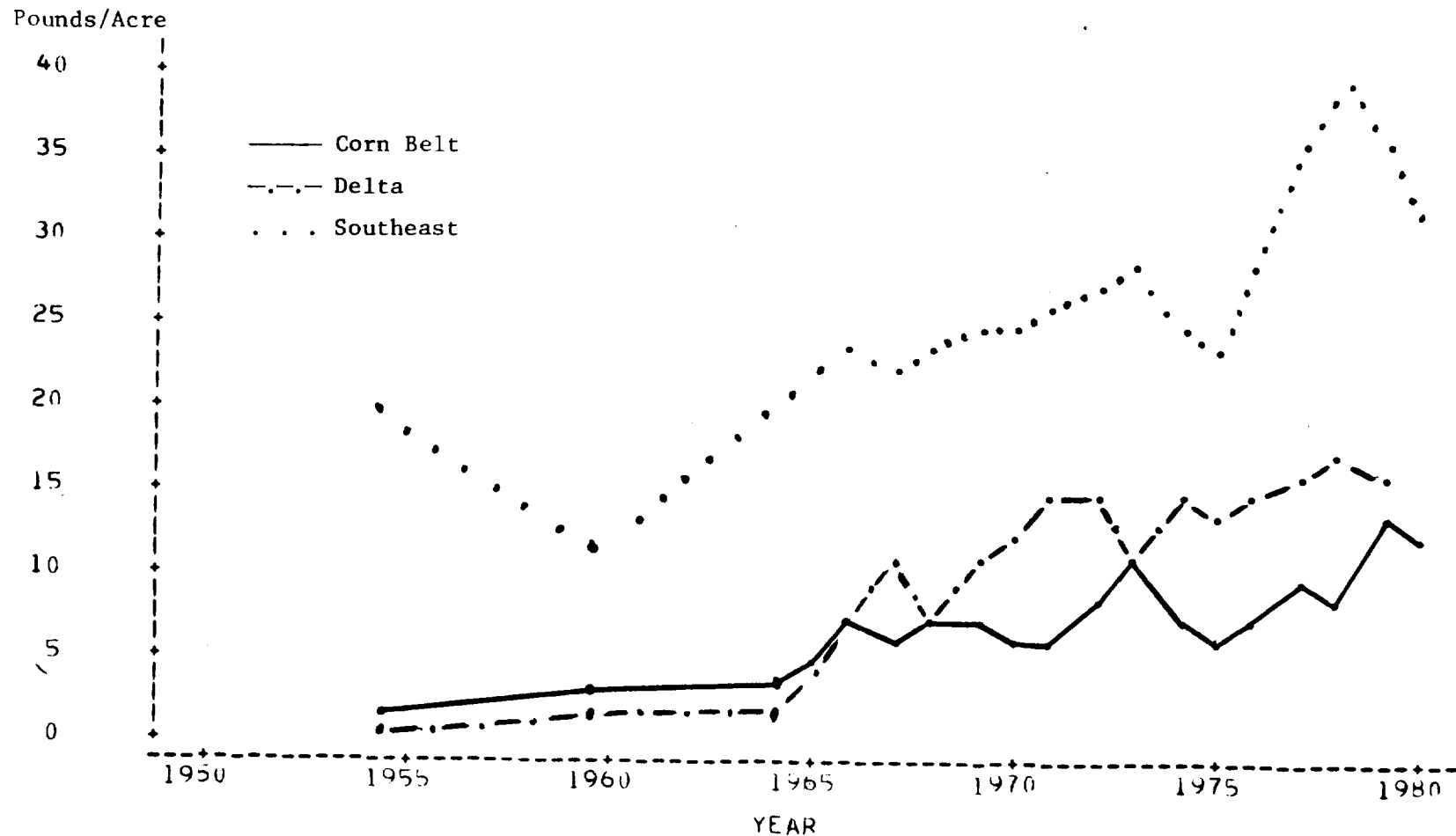
Figure 10. Pounds per acre of nitrogen fertilizers applied to soybeans, Corn Belt, Delta and Southeast Regions, 1954 to 1980^{1/}



^{1/} The rate of applied nitrogen fertilizer was calculated as a product of the proportion of acres receiving the nutrient and the pounds of available nutrient applied per receiving acre.

Source: The data for 1954 and 1959 are reported in reference nos. 81 and 82. The data for 1964 to 1980 are reported in reference nos. 78 and 80. From 1966 to 1976 the Southeast Region data includes only North Carolina, South Carolina and Tennessee and for 1978 it includes all states previously identified except South Carolina.

Figure 11. Pounds per acre of phosphorus fertilizers applied to soybeans, Corn Belt, Delta, and Southeast Regions, 1954 to 1980.^{1/}



^{1/} The rate of applied phosphorus fertilizer was calculated as the product of the proportion of acres receiving the nutrient and the pounds of available nutrient applied per receiving acres.

Source: Data for 1954 and 1959 are reported in reference nos. 81 and 82.

Data for 1966 to 1980 are reported in reference nos. 78 and 80.

the high phosphorus supplying soils occur in the northern and western portion of the Corn Belt while the Delta and Southeast have lower phosphorus supplying capability.

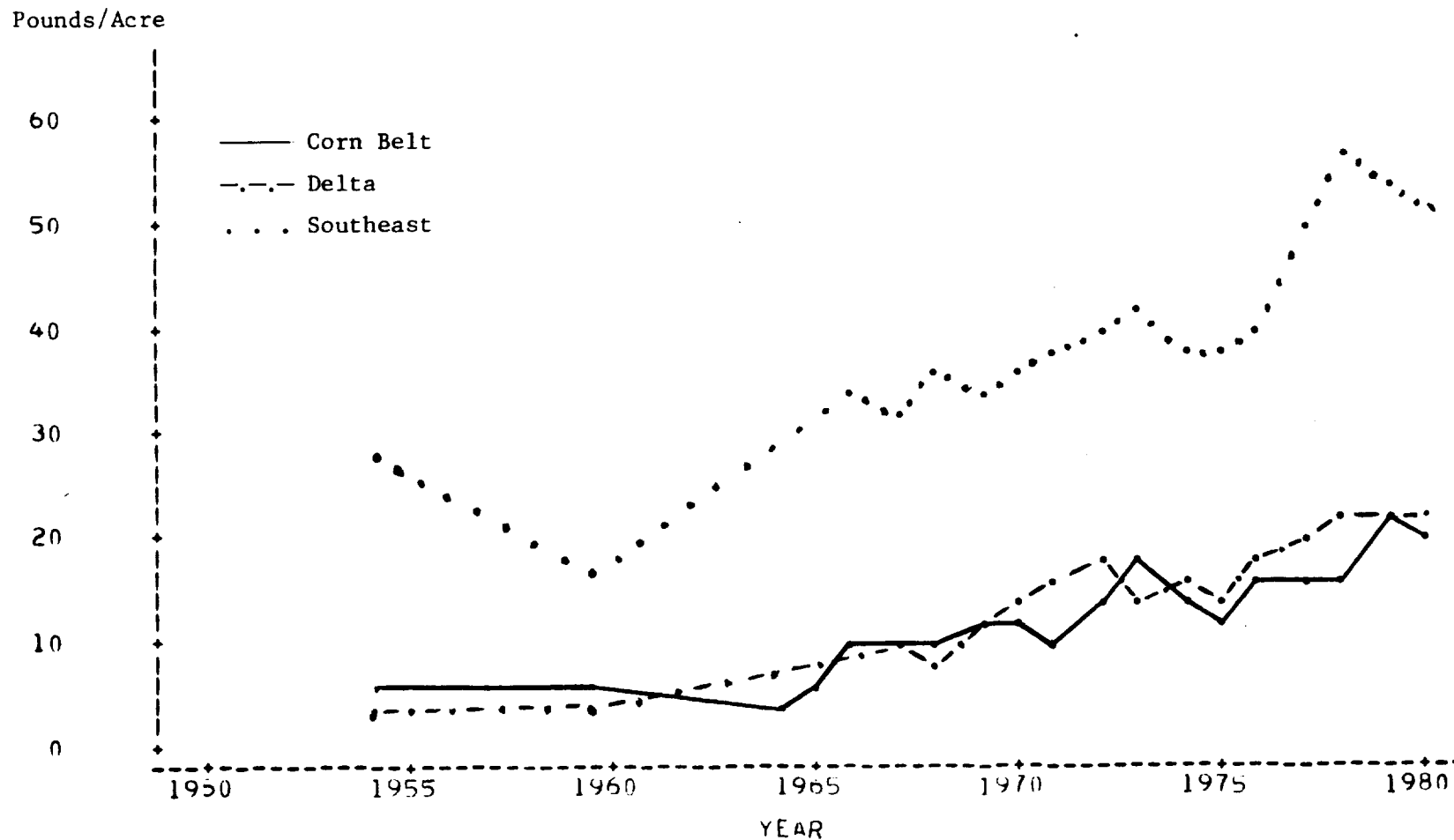
Maintenance level applications are primarily based on soybean yields. A bushel of soybeans removes approximately .85 pounds of phosphate and apparently the quantity does not vary significantly with yield levels [38]. Recent phosphorus applications per harvested acre (Figure 11) generally exceed such a maintenance level in the Southeast but fall short in the Delta and Corn Belt Regions. From 1975 to 1980 approximately .65 and .26 pounds of phosphate per bushel of soybeans was applied in the Delta and Corn Belt regions, respectively, while over 1.0 pound per harvested bushel was applied in the Southeast.

Potassium. Of the three major soil nutrients, potassium is often the most deficient for soybean production. Regional trends in application rates per harvested acre are illustrated in Figure 12. The highest rates, which occur in the Southeast, are generally more than double the rates applied in either the Corn Belt or Delta. The trends are similar in all three regions and follow the same pattern as that of other nutrients. An upward trend occurs from 1954, when annual data were first estimated, through 1970 and again in the late 1970's. In the period from 1971 through 1976, when first some shortages existed because of price controls and then dramatic price increases occurred after their removal, there was little growth in potassium application rates.

Yield response to varying levels of potassium fertilizer have been found significant only when soils test low or very low in nutrient availability. Higher yields, however, are associated with soils having high nutrient availability; consequently, a build-up and maintenance fertilizer program is recommended. Regional differences occur in the inherent potash supplying capacity of soils which affects the necessary application rates for build-up and maintenance. Generally, soils in the Southeast and Delta have lower potash supplying capacity than Corn Belt soils, thus requiring higher rates for build-up and maintenance. However, a wide range of differences does occur among Corn Belt soils affecting the need for potassium fertilizer. For example, western Iowa soils generally test medium to high in available potassium while northeastern Iowa soils test low or very low [38]. In Illinois the northern two-thirds of the state has a higher potassium supplying capacity than the southern part of the state [90].

Because most of the available potassium in the soil is in an exchangeable form and relatively immobile, the nutrient loss is primarily that contained in the harvested crop. A bushel of soybeans removes approximately 1.1 pounds of potassium [38]. Potassium application rates per harvested acre fall short of this crop removal level in the Delta and Corn Belt, but generally exceed the crop removal in the Southeast. These rates, however, do not necessarily imply a build-up or depletion of the nutrient in the soil because the fertilizer is also applied to alternate crops often grown in rotation with soybeans.

Figure 12. Pounds per acre of potassium fertilizer applied to soybeans, Corn Belt, Delta and Southeast Regions, 1954 to 1980.^{1/}



^{1/} The rate of applied potassium fertilizer was calculated as the product of the proportion of acres receiving the nutrient and the pounds of available nutrient applied per receiving acre.

Source: Data for 1954 and 1959 are reported in reference nos. 81 and 82.
Data for 1966 to 1980 are reported in reference nos. 78 and 80.

Genetic Improvements

The development and adoption of new corn hybrids and soybean varieties have been hypothesized as another significant technological component contributing toward the trend of increasing yields. Improvement efforts have been not only to select for higher yields under favorable environments but also for characteristics which minimize yield reductions under adverse conditions. Some varieties and hybrids are developed and adopted because of their response to high fertilization, irrigation, chemical herbicides, minimum tillage, double cropping, mechanical harvesting or other production practices. Sorting out the contribution of hybrid or variety improvement independent of these other practices is a difficult task. Some research effort, however, has been made to develop time series indices reflecting variety and hybrid improvement.

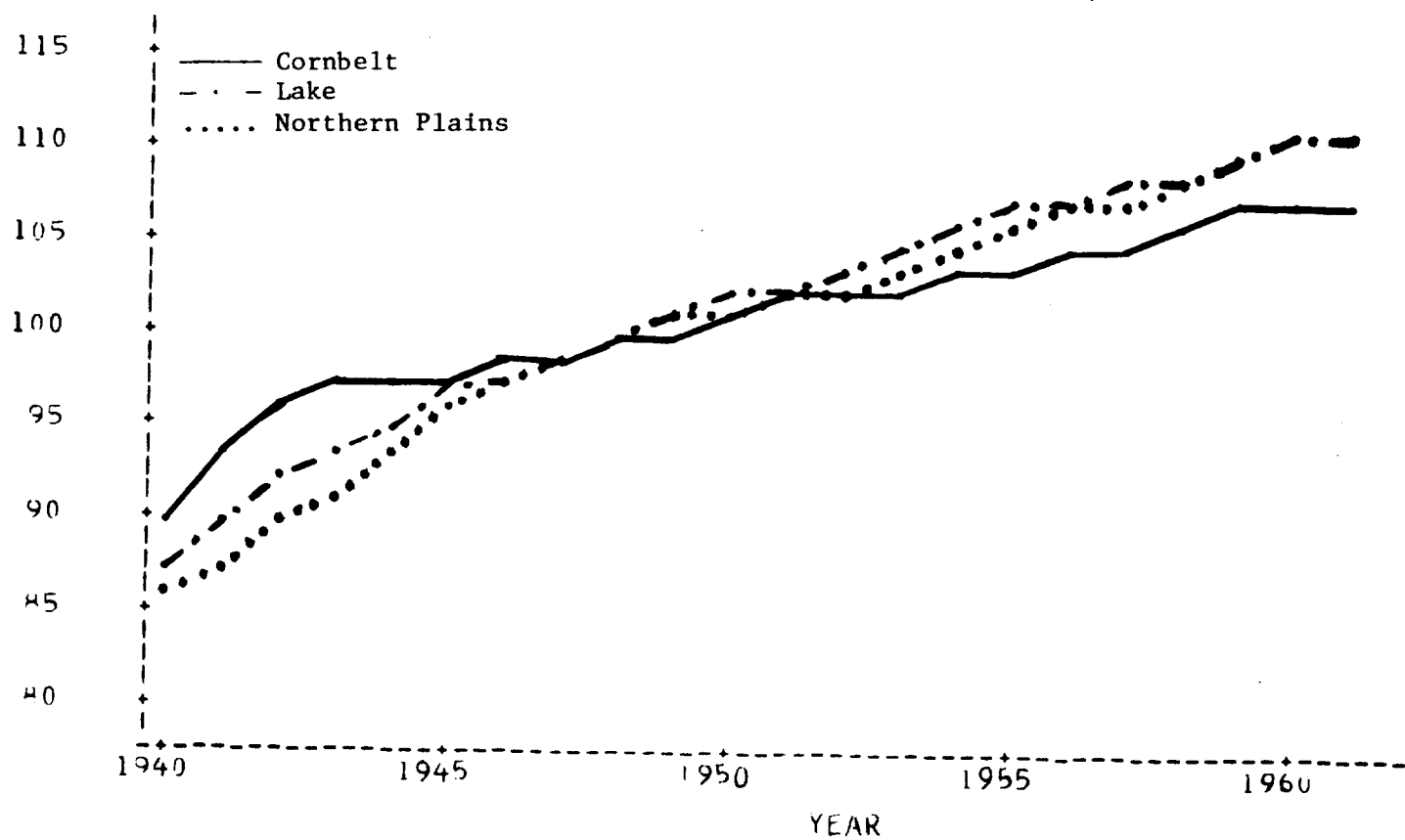
Corn

Prior to 1930 improvements in corn varieties were limited to the selection among open-pollinated varieties. The widespread availability and the beginning of the adoption of commercial hybrid seed began about 1935. Within the next ten years nearly 100 percent of corn acreage in the Corn Belt states was planted to hybrid seed. A commonly assumed yield influence of the early hybrid seed corn over open pollinated varieties was a 15 to 20 percent increase with little difference among high and low yield areas [25]. The continued introduction and adoption of improved commercial hybrids lead to further increases in yield. Breeders have selected hybrids for a number of characteristics leading not only to higher yields under favorable weather and farming practices, but also moderating yield reduction under conditions of adverse weather, disease or pests.

Several studies have been made to estimate the yield impact from corn hybridization with quite different results. An early study by Griliches [25] which focused on adoption rates and a yield differential between all hybrids, reported a 7 bushel per acre increase in Corn Belt yields prior to 1950 from hybridization. Shaw and Durost estimated the impact of hybridization to be 16 to 18 bushels per acre for the period from 1929 to 1962 [65]. Alternatively, Johnson and Gustafson estimated the contribution at only 3 to 4 bushels per acre [40]. A 9 bushel per acre yield increase was credited to hybridization for the period 1939 to 1961 in a study by Auer and Heady [4]. In a later study by Heady and Perrin [32], however, they suggest that added fertilization made a greater contribution and hybrids alone contributed only about 6 bushels per acre. Because new hybrids have partially been selected for their response to high fertilization, it is not generally feasible to ascertain whether the yield increase results from seed improvements or higher fertilization rates.

An example of a corn hybridization index developed by Auer and Heady is illustrated in Figure 13. They developed state indices from yield performance tests comparing individual hybrids in each state with marketing data reflecting first the adoption of hybrids and later the replacement of

Figure 13. Corn hybridization indices for the Corn Belt, Lake and Northern Plains Regions, 1940 to 1961 (1947 = 100).



Source: These indices and procedures of derivation are reported in reference no. 4.

older hybrids with improved, higher yielding ones. Although regional performance data on new hybrids is available to extend this trend to the current period, the marketing data which measures the adoption of recent hybrids is generally not available. These data indicate a relatively constant rate of improvement between 1950 and 1961 in all regions, but a slightly lower rate of improvement in the Corn Belt than in the Lake or Northern Plains Region.

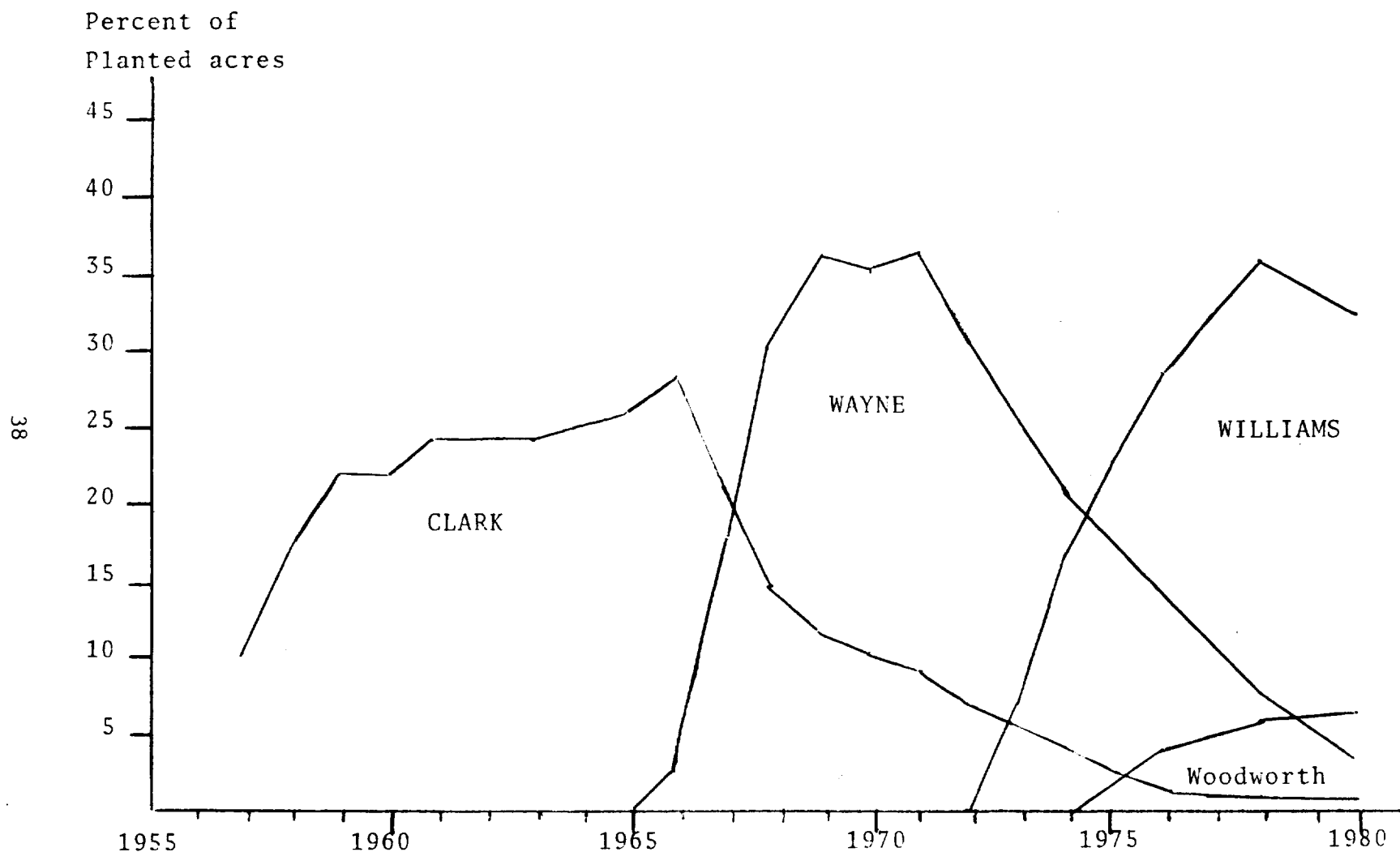
Soybeans

With the increased economic importance of soybeans has come added research efforts to develop new and improved varieties. The Plant Variety Protection office has issued approvals on over 100 new varieties since 1970. The new varieties have been developed by both public and private researchers. The variety development goals have been not merely to increase yields but to develop varieties which complement specific cultural or management practices, have resistance to pests and disease, and maintain desired seed quality characteristics. Some varieties, as a consequence, respond better than others to narrow rows or solid seeding, double cropping, irrigation or other practices. Selected yield performance and variety adoption data are reported in this section to indicate the potential yield impacts of variety improvements since the mid 1950's.

The soybean plant is photo-period sensitive, thus certain stages of development are in response to the length of darkness (or daylight) in a 24 hour period. Varieties are, therefore, basically limited to specific geographic latitudes. Soybean varieties have been grouped into ten maturity classes with each class corresponding to an east-west band across the U.S. The varieties grown for beans in the Corn Belt include Classes I to V while those grown in the Delta and Southeast include Classes IV to VIII. There is no clear boundary where a variety class may or may not be grown and weather conditions or cultural practices result in some varieties being grown outside their generally identified boundary. When addressing the influence of variety improvement or the replacement of older varieties with new ones, it is important to consider the individual maturity zones, since a new variety is adaptable only to a limited geographic area. Soybeans are also classed as determinate and indeterminate varieties. Stem elongation and the growth of some other plant components stop at a certain development stage in the determinate varieties, leading to somewhat shorter and more uniform plants. In general the determinate varieties are grown in the Delta and Southeast regions, but certain varieties are available for use in the Corn Belt Region and are being adopted under solid seeding and double cropping practices.

Figures 14 and 15 illustrate the dominant soybean varieties that have been grown in Illinois from 1956 to 1980. Figure 14 indicates the percent of planted acres in the later maturing varieties (Classes III and IV) which are predominantly grown in the central and southern parts of the state. Three public varieties, Clark, Wayne and Williams, had a definite era when they were the dominant variety. Clark was a common variety grown from 1956 to 1968. From 1966 to 1968 Wayne replaced Clark and from 1972 to 1975 Williams replaced Wayne in the central and southern portion of the state. Yield performance tests indicate a yield advantage to the replacing varieties [90].

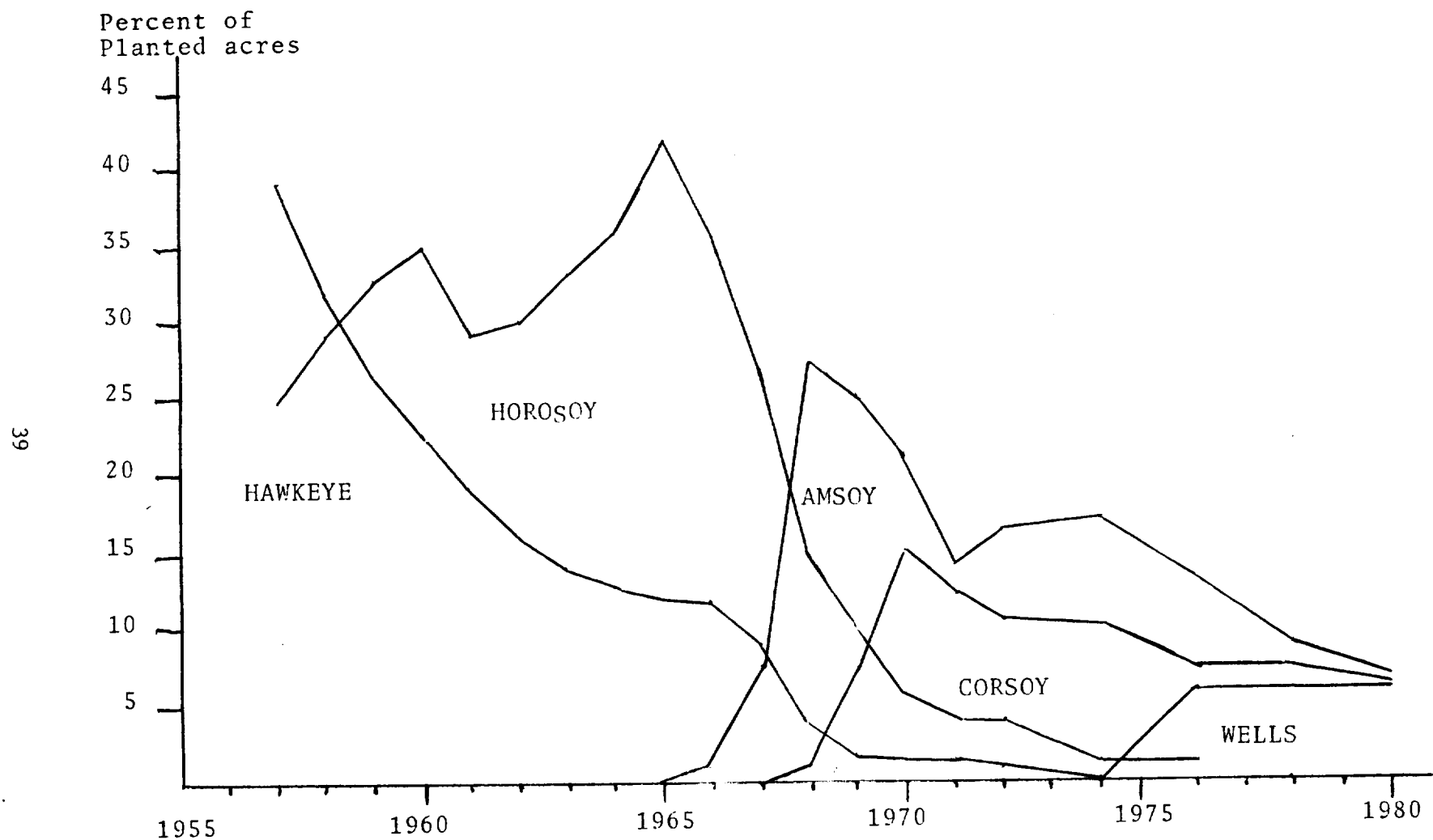
Figure 14. Percent of Illinois Soybean Acreage Planted to Later Maturing Varieties, 1957 to 1980.^{1/}



^{1/}Includes varieties in maturity classes III and IV.

Source: These percentages were reported by the Illinois Cooperative Crop Reporting Service and represent the percentage distribution of acreage planted on farms of crop reporters.

Figure 15. Percent of Illinois soybean acreage planted to earlier maturing varieties, 1957 to 1980.^{1/}



^{1/} Includes varieties in maturity classes I and II.

Source: These percentages were reported by the Illinois Cooperative Crop Reporting Service and represent the percentage distribution of acreage planted on farms of crop reporters.

Six years of tests at six Illinois locations reported Wayne having a 2.7 bushel per acre yield advantage over Clark. Likewise, performance tests report Williams outyielding Wayne by an average of 1.8 bushels per acre in three years of testing.

Figure 15 indicates the percent of planted acres in earlier maturing varieties (Class II) which are grown predominantly in central and northern Illinois. Hawkeye was the dominant variety in the early 1950's. Horosoy gradually replaced Hawkeye and remained the dominant variety until the introduction and adoption of Amsoy in the late 1960's. Since 1970 other public varieties as well as an increasing number of private varieties and blends have been planted and no single variety has dominated. Yield performance tests indicate a yield advantage of Horosoy over Hawkeye and Amsoy over Horosoy, but little significant difference between Amsoy, Corsoy, Wells and some other competing varieties. In five test years at Illinois sites, Horosoy outyielded Hawkeye by 2.4 bushels per acre. In six test years and six sites, Amsoy outyielded Horosoy by 2.9 bushels per acre. Performance test yields averaged over six years at Urbana and Elwood, Illinois were 45.0, 45.8, and 46.3 bushels per acre for Amsoy, Wells and Corsoy, respectively.

Changes in leading varieties in other Corn Belt states occurred in a somewhat similar sequence to those in Illinois. In the late 1960's and early 1970's Wayne, Horosoy and Amsoy were also the most common planted varieties in Ohio, Indiana and Iowa. Williams, Corsoy and some private varieties replaced these in the following years. In Missouri, Clark was the dominant variety from 1966 to 1975 and Williams was dominant from 1976 to 1981. In the Delta and Southeast, the replacement of the most common varieties has been gradual. In 1967 Lee was the most common variety throughout the Delta and most of the Southeast, accounting for over 50 percent of the planted acres in several states [78]. Its use gradually declined in the early 1970's and accounted for 14 percent of the acreage in 1976. Bragg, Davis, Forrest and Ransom are among the most common varieties replacing Lee in the Delta and Southeast.

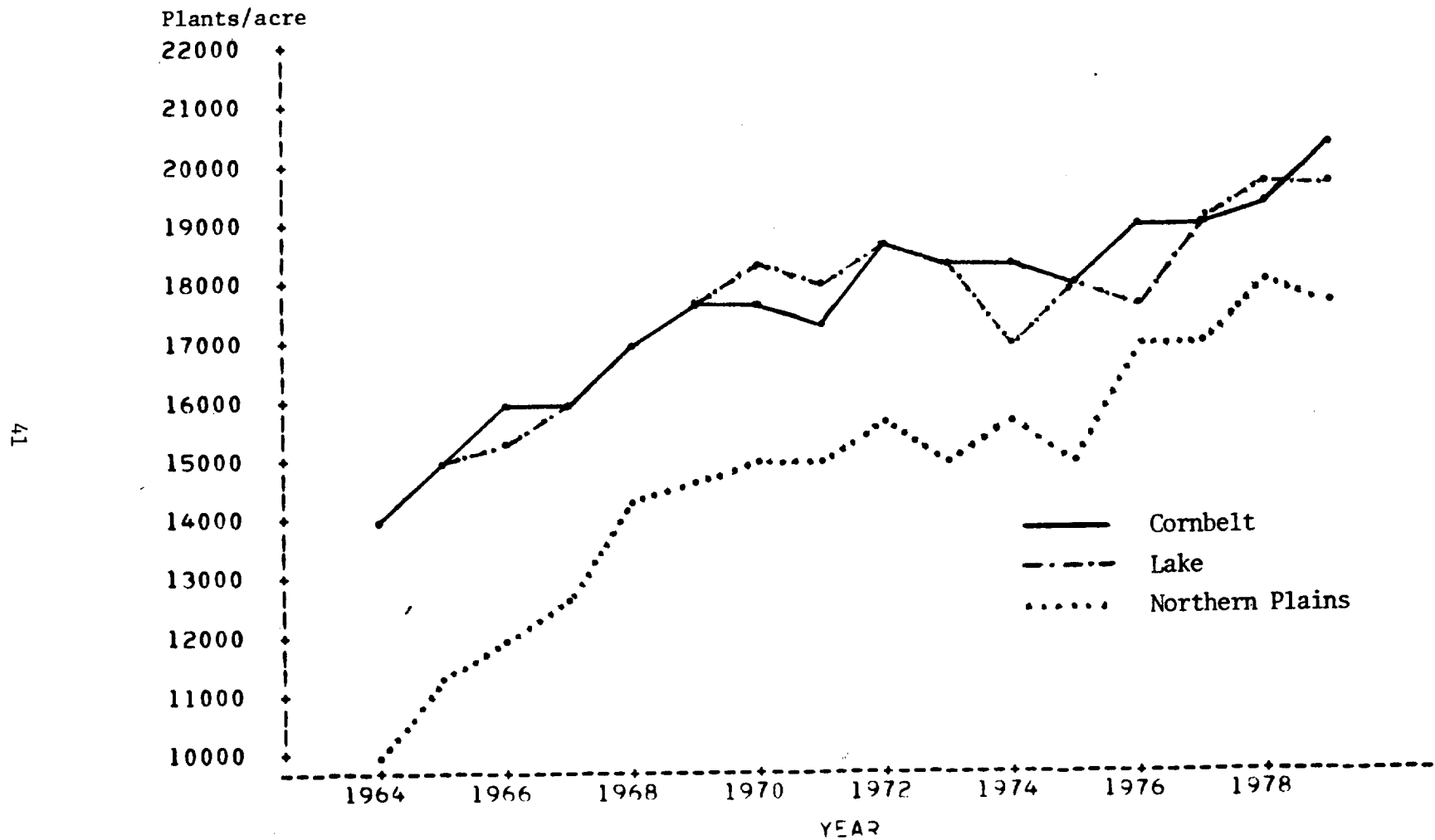
Plant Population and Row Spacing

With sufficient soil moisture, the potential for increased yields exists with higher plant densities. Plant breeding efforts for both corn and soybeans have been toward developing hybrids and varieties which tolerate higher density without lodging or having partially or completely barren stalks. Also, the use of chemical weed control and changes in machine components have allowed farmers to reduce row widths as a means of increasing plant population per acre. Recent trend data on plant populations and row widths are presented in this section as well as a short discussion of site specific yield impacts from alternative plant populations and row spacings.

Corn

Average plant populations per acre in the Corn Belt, Lake and Northern Plains Regions since 1964 are illustrated in Figure 16. While population density in the Corn Belt and Lake Regions is nearly equal, lower densities occur in the Northern Plains. Plant population per acre in the Northern Plains since 1964

Figure 16. Corn plant population per acre in the Corn Belt, Lake, and Northern Plains Regions, 1964 to 1980.



Source: These data are reported in reference no. 78.

has averaged approximately 15 percent less than in the Cornbelt and Lakes Regions. In recent years, however, the gap has closed slightly and the average difference from 1978 to 1980 was only 10 percent.

Although there are regional differences in plant population density, the general trend is quite similar in all three regions. The increase in the Corn Belt and Lake Regions has been from approximately 14,000 plants per acre in 1964 to 20,000 in 1980, and the increase in the Northern Plains was from approximately 10,000 plants per acre in 1964 to nearly 19,000 in 1980. The fastest increase, which was about 4 percent each year, occurred from 1964 to 1970. During the early 1970's, a plateau was reached with little increase in plant density occurring in any region. However, since 1975, the trend has continued upward, but at a somewhat lower rate [78].

Higher plant populations have been achieved by both decreasing the distance between plants within a row and decreasing row width. Potential yield increases from decreasing distance between plants within a row are limited to the lower plant population levels. To further increase their yield potential, farmers have adopted narrower rows. Narrower rows develop a full canopy earlier in the growing season, thus taking better advantage of solar energy and providing shade to conserve soil moisture [62]. Traditionally, row widths of approximately 40 inches have been used and most planters, field cultivators and harvesting equipment were designed according to this standard. Consequently, the adoption of narrower row technology has required some adjustment in machine components and additional investments.

Although little regional difference occurs in the rate of adoption of narrower rows, some states do lag in using this technology. For example, in the eastern Cornbelt states of Ohio and Indiana, the 1980 average row width was approximately 33 inches, while in Iowa and Missouri it was 35 inches. A wider difference occurs in the Northern Plains with Kansas, producing mostly irrigated corn, having an average width of 31 inches and North Dakota having an average width of 38 inches.

Potential yield impacts occur with changes in plant population due to distance between plants within the row and row widths. The yield effect, of course, will vary with many other factors including fertility, weather, and seed variety. Research in Missouri, under favorable growing conditions of 1967 and 1968, suggests that yields increased with an increase in population from 16,000 to 24,000 plants per acre and no change in row width. There was little yield advantage to populations greater than 16,000 under less favorable conditions in 1966 [54]. Positive yield impacts also occurred as row width was decreased from 40 to 30 inches. Although twenty inch rows can potentially grow more than 30 inch rows, it is suggested that farmers are not likely to realize any gain in harvested yield due to difficulties in weed control and in harvesting [54]. In Illinois, both narrower rows and increased population have positive influence on yield, at least up to a point. Table 5 indicates the effect of row width and plant population as investigated by the University of Illinois at Urbana.

Table 5. Row width and plant population impact on corn yield,
Urbana, Illinois, 1981

Plant Population	Row Widths	
	40"	30"
Plants/acre	-- Bushels/acre --	
16,000	127	132
27,000	133	144
32,000	126	138

Source: Reference no. 89.

Soybeans

Row widths have a potential influence on soybean yields. Figure 17 illustrates the trend toward narrower rows in the Corn Belt since 1966 and in the Delta states of Arkansas and Mississippi since 1972. Row width data have not been consistently reported for Louisiana and the states in the Southeast Region. Calculation of average row width does not include fields of soybeans which were broadcast planted.

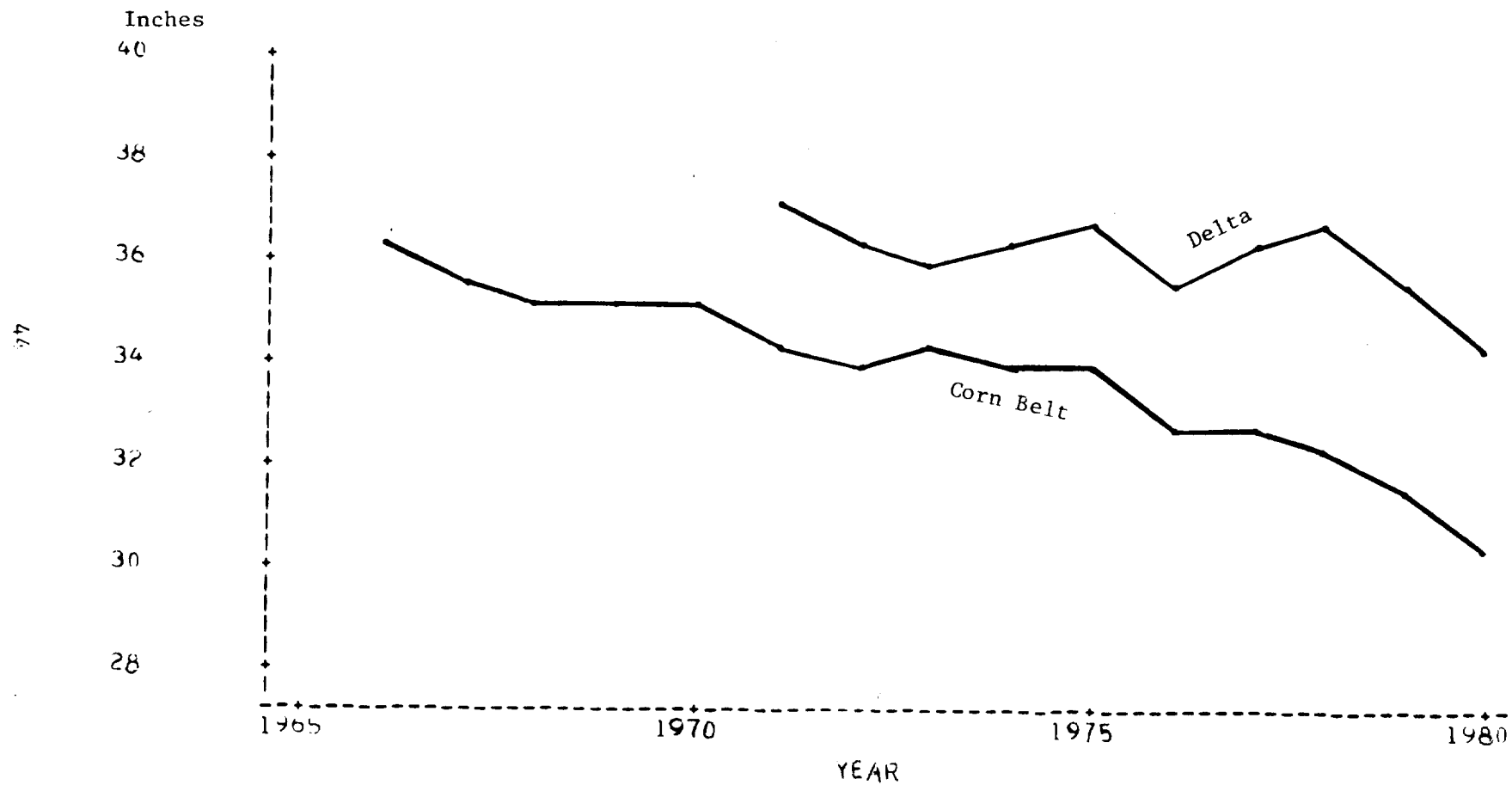
The trend in average row width stems from several somewhat different production practices. Some farmers are reducing row widths from 40 down to 28 inches. This reduction, similar to that of corn, can be adopted with certain adjustments in the planter to reduce row widths. Other practices, including skip row planting, use grain drill or modified conventional planters to further reduce row widths down to 15 inches. Solid seeding, generally defined as row widths less than 15 inches, has recently become a more common practice and includes soybeans which are either broadcast or drilled in rows which are too narrow for field cultivation.

From 1966 to 1974 over 90 percent of the soybean acres in Indiana, Illinois, Iowa and Missouri were in rows wider than 28.5 inches. In Ohio a considerably smaller proportion of the soybeans has been grown in rows wider than 28.5 inches. From 1966 to 1981 the percentage of Ohio soybeans in row widths wider than 28.5 inches decreased from 78 to 50 percent.

Since 1977 a significant proportion of soybeans has been solid seeded, i.e., grown in rows under 10.5 inches in width. Table 6 indicates the percentage of soybeans solid seeded in the Cornbelt and Delta states. In 1981 it was estimated that over 15 percent of the Corn Belt soybean acreage was solid seeded, a 3.4 million acre increase from five years earlier. In the Delta states approximately one-fourth of the soybean acreage is solid seeded.

It is generally agreed that reductions in soybean row width along with proper management and variety selection will increase soybean yields per acre. The response has been shown to vary among varieties, planting date, herbicide application, geographic area and weather. The largest yield response occurs with solid seeding and has generally been in the range of a 10 to 30 percent

Figure 17. Soybean average row widths, Corn Belt Region and selected states in the Delta Region, 1960 to 1980.^{1/}



^{1/}Delta Region includes Arkansas and Mississippi.

Source: The data are reported in reference nos: 78 and 80.

Table 6. Percent of soybean acres which are solid seeded,
Corn Belt and Delta Regions, 1977 to 1981^{1/}

State	1977	1978	1979	1980	1981
----- Percent -----					
Corn Belt	4.6	5.2	6.7	9.7	15.3
Ohio	22.3	22.6	28.1	31.9	37.2
Indiana	1.9	5.4	3.3	9.1	12.0
Illinois	2.5	2.4	5.2	5.4	17.6
Iowa	1.0	.7	.7	2.8	3.5
Missouri	2.9	3.8	5.1	12.6	17.6
Delta	2/	10.0	14.9	27.8	26.6
Arkansas	5.3	4.3	12.9	21.2	12.0
Louisiana	2/	14.1	23.9	27.2	33.3
Mississippi	12.1	14.5	10.1	24.8	21.0

^{1/} Includes soybeans planted in row widths of 10.5 inches or less.

^{2/} Not available.

Source: Reference no. 78 and 80.

increase [72]. The yield increase from adopting narrow rows which allow inter-row tillage is usually somewhat less than that for solid seeding. Table 7 indicates the average yield response to reductions in row widths obtained under various research environments. Although the yield response to widespread adoption by farmers may differ somewhat, the responses shown in Table 7 provide an estimate of potentials with reductions in row widths under excellent management.

Table 7. Soybean yield response to reductions in row widths,
various research locations and years

Location	Inclusive years	Change in Width from To		Yield Response
Urbana and Saybrook, Il.	1973-75	30"	7"	+26%
Lafayette In.	1975-77	36"	6"	+15%
Arlington, Wi.	1975-77	30"	16"	+21%
Nashua, Ia.	1976-79	40"	15"	+27%
Lincoln, Ne.	NA	40"	10"	+48%
Wooster, Oh.	1977-79	30"	7"	+27%

Source: Reference no. 1.

Research in several states appears to indicate significant variety-row width interactions. The earlier maturing, semi-dwarf and open canopy varieties have had a greater response to narrow rows than later maturing, tall, and large canopy varieties. In Indiana, trials were made comparing semi-dwarf varieties with tall, large canopy varieties under alternative row widths [72]. Of the nine varieties tested, all produced larger per acre yields in solid seeding and 18 inch intertilled rows than they did in 36 inch rows. The yield response ranged from 2 to 14 bushels per acre. For the large variety types (Williams and Union), the yield response was greatest with 18 inch intertilled rows while the yield response of the smaller varieties was generally greatest with solid seeding. In Ohio, the yield response of new, lodging resistant, semi-dwarf varieties to row width reductions was in the range of 30 to 40 percent while the yield increase of the larger and more widely used varieties was only 10 to 20 percent [12]. When planting date is delayed, the yield response appears to be greater for narrow rows than when planting occurs early in the season. At Arlington, Wisconsin, a 17 percent yield response occurred with width reductions (30 to 7 inches) when planted in early May, but when the planting date was delayed to early June, the yield response was 23 percent even though actual yields were less [59]. Accordingly, yield response appears to vary by maturity group and corresponding geographic areas. At the northern Illinois soybean variety test site of Elwood where mostly maturity group II varieties are grown, 1979 varieties tested in 7 inch rows yielded an average of 23.8 bushels per acre more than in the 30 inch rows [90]. At the southern Illinois test site of Brownstown, where mostly maturity group III and IV are grown, the 7 inch rows outyielded the 30 inch rows by only 3.4 bushels per acre for group III varieties and 2.1 bushels for group IV varieties.

Pesticides

Since the early 1950's there has been widespread adoption and increased use of chemicals to control weeds and insects in corn and soybeans. According to the 1976 National Pesticide Survey [19], 90 percent of the corn and 88 percent of the soybean planted acres were treated at least once with a herbicide. Insecticides are used to a lesser extent, with only 38 percent of the corn and 7 percent of the soybeans treated. The use of fungicides, growth regulators and other pesticides has been limited to only 2 percent of the corn and 4 percent of the soybean acreages.

Herbicides

Competition from weeds for water, light and nutrients affect crop yields and, when that competition is removed by either mechanical methods or herbicides, a positive yield response is anticipated. Herbicides were initially adopted as a partial substitute for labor and equipment in mechanical weed control. The yield response, if any, depended upon the weed control performance of the herbicide relative to that of field cultivators, crop rotation and other mechanical practices previously used to control weeds. Because the first introduced herbicides were not effective on all problem weeds, they only reduced the need for certain mechanical practices. The improved performance of later herbicides which control most problem weeds and grasses further eliminated the need for mechanical weed control and opened the way for the adoption of more optimal spacing and other technologies having positive impacts on yield or providing cost savings.

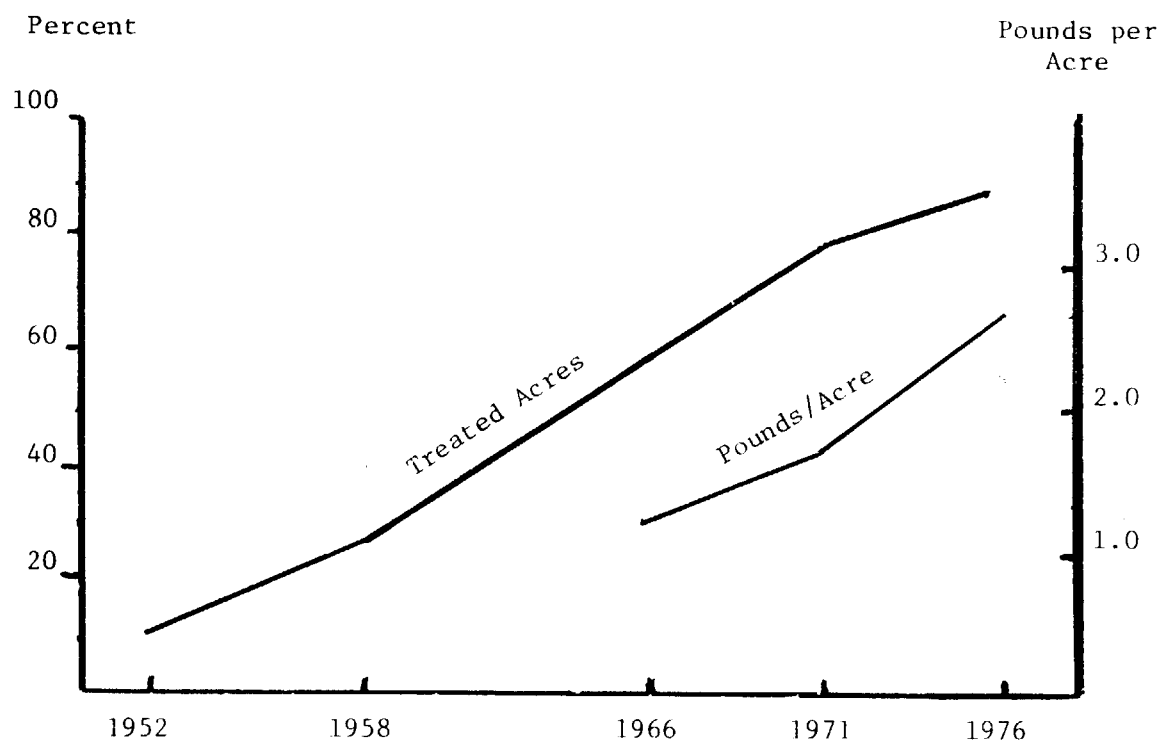
Effectiveness of herbicides used on corn and soybeans is quite variable depending upon not only the herbicide or herbicide mixture applied, but also on weather, soils, time of application, and kind of weeds needing control. A number of the preplant and preemergence herbicides need to be incorporated into the soil and kill weeds upon germination. These herbicides often require sufficient rain soon after application to activate the herbicide; however, excessive rain can reduce the effectiveness. Post emergence herbicides often kill upon foliar contact, and rainfall immediately following application reduces effectiveness. Also postemergence herbicides need to be applied at specific growth states to avoid crop injury. While some herbicides control both annual grassy weeds and broadleaf weeds, others are more selective. Herbicide mixtures and multiple treatments are often recommended for specific weed problems.

Corn. Figure 18 illustrates the increased use of herbicides on U.S. corn. Between 1952 and 1976, treated corn acres increased from 11 to 90 percent. Simultaneous with this increase in treated acres were increases in the application rates. In the ten years from 1966 to 1976 the pounds applied per treated acre increased 125 percent, reflecting increases in multiple treatments as well as increased rates per treatment.

Figure 19 illustrates the extent of the most used herbicides on corn from 1964 to 1976. Prior to 1950, chemical weed control consisted primarily of inorganic acids and salts which were used to kill all existing vegetation prior to the crop production season. Since 1950, numerous organic type herbicides became available and provided selective weed control from applications during the crop growing season. Among the early organic herbicides, 2,4-D became the most widely used on corn. In 1953, weed scientists [69] estimated that approximately 5 percent of Indiana, Illinois and Iowa acreage was treated with 2,4-D. In 1964, the earliest year survey data were available for specific crop use, approximately two-thirds of the U.S. corn acreage was treated. Although 2,4-D continues to be used on corn and is effective in controlling many weeds, it allows many grasses and resistant broadleaf weeds to flourish. As better performing herbicides became available in the 1960's and 1970's, the use of 2,4-D began to diminish and in 1976 only 15 percent of the corn acreage was treated.

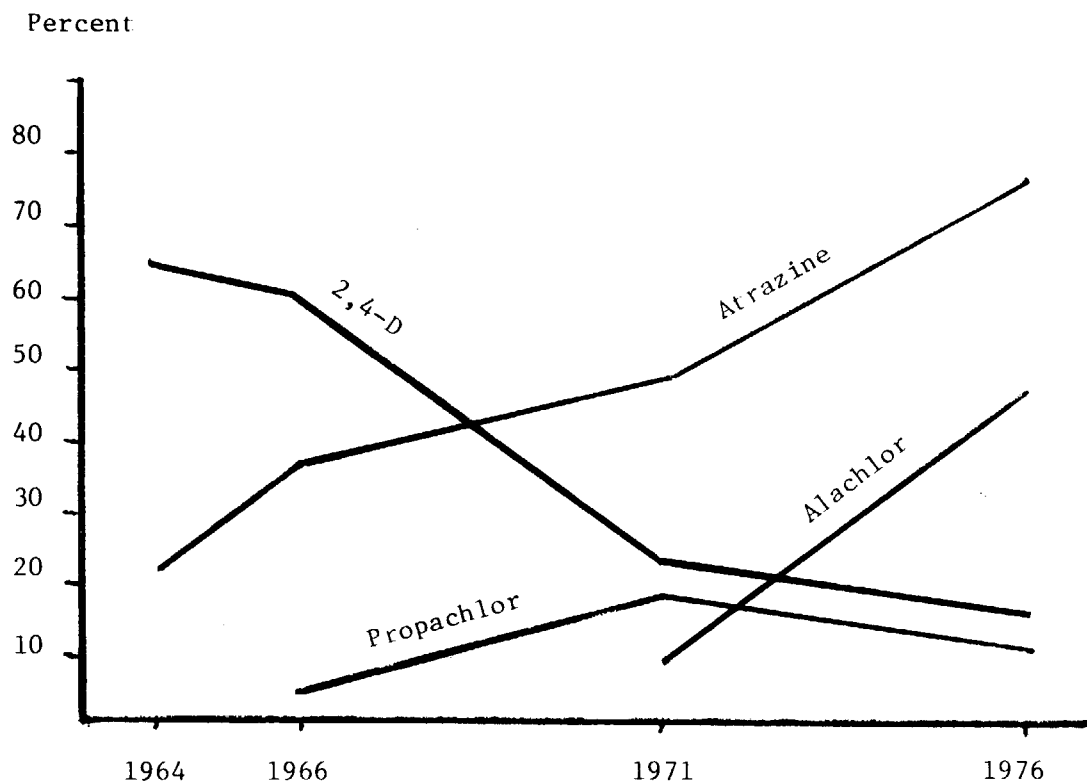
The later developed herbicides included those which can be directly applied to the crop or incorporated into the soil prior to planting and provide early and long lasting weed control. Atrazine and more recently alachlor have been the herbicides most commonly used on corn. The use of atrazine increased from 11 percent of planted acres in 1964 to 67 percent in 1976. The use of atrazine, however, precludes planting small grains, vegetables or legumes in the following year, and lower application rates are recommended if soybeans are to be the following crop. Mixtures of atrazine with some other chemicals or the exclusive use of less residual chemicals have provided equal or superior performance to atrazine applied as a single herbicide in recent years. Alachlor, having less residual effect, has been the second most commonly used chemical on corn in recent years. In 1976, 40 percent of the planted corn was treated with alachlor or an herbicide mixture containing alachlor.

Figure 18. Percent of corn acres treated with herbicides and the average application rate per treated acre, United States, 1952 to 1976.



Data Source: Reference no. 3, 19 and 21.

Figure 19. Leading herbicides applied to corn as a percent of treated acres, United States, 1964 to 1976.



Source: Reference nos. 3, 19 and 21.

The corn yield response over the last thirty years from the adoption and increased use of herbicides is difficult to measure and has not been widely researched. For a large part, herbicides have been adopted because of their cost savings over mechanical weed control measures. The yield response results from the superior performance of herbicide treatments over the previously applied mechanical and cultural practices. Some test plot research studies, however, do provide some indication of potential yield impacts from improved performance of herbicides over mechanical field cultivation.

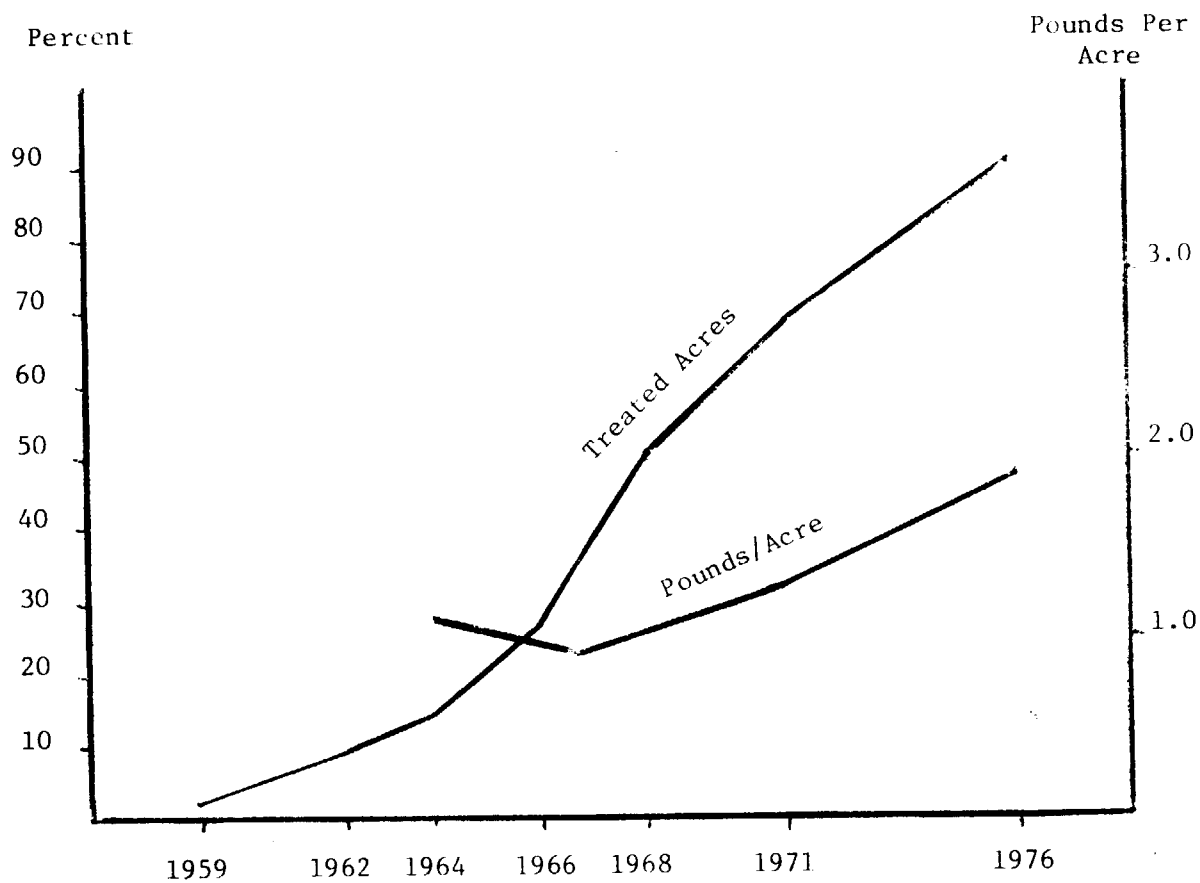
Staniforth studied corn yield losses in Iowa from weed infestations after three or four field cultivations on 166 plots from 1950-1953 [71]. He reported weed infestations of the magnitude of 500 pounds per acre of dry matter were rather common following such good mechanical weed control practices and that yield reduction of six to eight bushels per acre occurred compared to yields in clean, hand-weeded check plots. The yield loss on test plots was rather constant despite ranges in the base yields from 71 to 116 bushels per acre. At that time he estimated that approximately five of the eight bushels lost were recovered with 2,4-D herbicide treatment. Under heavier weed infestations and less intensive mechanical weed control, larger potential yield impacts were observed. More recent herbicide performance studies show equal or larger potential yield response to herbicide treatments; however, they involved less intensive field cultivation. In Wisconsin, the 1978-80 mean yield increase of herbicide treatments over two cultivated check plots was 15.5 bushels per acre [68]. Yields in Minnesota on herbicide treated plots from 1978-80 averaged 30 bushels per acre more than the single cultivated plots [51].

Soybeans. The adoption of herbicide technology on U.S. soybeans began about 1960. In 1959, only 2.5 percent of the soybean acreage was treated with any herbicides for weed control. As illustrated in Figure 20, the extent of herbicide use as well as application rates per treated acre increased in the following seventeen years. The 1976 survey indicated approximately 88 percent of all soybeans received herbicide treatments, with little regional difference in the extent of use. The Corn Belt reported 92 percent treated while the Southeast and Delta states reported 88 percent treated [19].

Although numerous chemicals are available for weed control on soybeans, a few herbicides can account for the major proportion of treated acres. Figure 21 indicates the percent of treated acres where various leading herbicides were applied. From 1964 to 1971, amiben was the most commonly used herbicide on soybeans, accounting for 31 to 41 percent of the treated acreage. In 1976 trifluralin was the leading herbicide and was applied singly or as a mixture on 55 percent of all treated acres. The use of alachlor, which is often used in mixture with other herbicides, increased almost five fold from 1971 to 1976 and was applied to 42 percent of the treated acres in 1976.

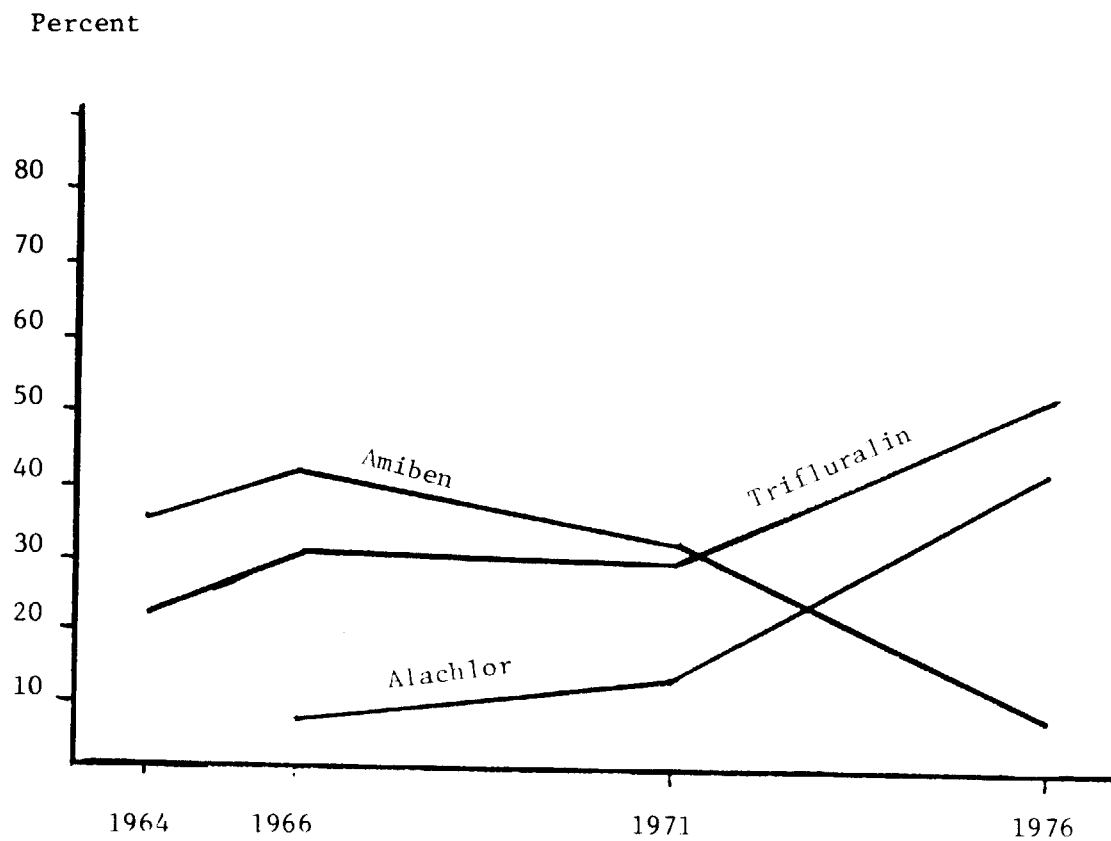
Advances in weed control technology for soybeans have made possible the adoption of yield increasing cultural practices while reducing losses from weed infestation. Solid seeded soybeans, which preclude inter-row tillage, and reduced tillage systems for soil conservation are possible only with

Figure 20. Percent of soybean acres treated with herbicides and the average application rate per treated acre, United States, 1959 to 1976.



Source: Reference no. 3, 19, 20, 21 and 79.

Figure 21. Leading herbicides applied to soybeans as a percent of treated acres, United States, 1964 to 1976.



Source: Reference nos. 3, 19, 20 and 21.

extensive use of herbicides. In addition to the potential yield impacts discussed elsewhere from the adoption of these practices, some gains can independently be attributed to improved chemical weed control over the previous mechanical weed control methods.

A number of herbicide performance studies on soybeans indicate that most problem weeds can be controlled by herbicides which provide a positive yield response. In some studies the yields on experimental plots can be compared to cultivated and weed free (hand weeded) check plots to measure potential yield impacts. In Illinois in 1980, with favorable rainfall following preemergence applications, the mean yield on 68 treated test plots was almost equal to the yield on the weed free plots, but nearly 30 percent or nine bushels per acre higher than the yield from cultivated checks [42]. In 1978 and 1979 the mean yields on treated plots were 7 and 29 percent respectively less than on the weed free plots, while yields on the cultivated plots were 36 and 60 percent respectively less than on the weed free plots. It should be noted that on the cultivated plots, little effort was made for timely and effective weed control; consequently, the yields were lower than one would normally expect with good mechanical practices. Similar herbicide performance studies in Minnesota [51] and Wisconsin [27] suggest that yields on herbicide treated plots approximate those on weed free plots but exceed the yields on cultivated test plots.

Insecticides

The use of insecticides to reduce yield losses from insect pests has also been identified as a factor contributing to the upward trend in crop yields. Since 1950, there has been increased use of various insecticides to control infestations in corn and soybeans throughout the growing season. Because of the development of insect resistance to some insecticides, the introduction of new insect pests and the suspension of certain chemicals for crop use, some significant changes have been made in pesticide use. Because of differences in the kinds of insect pests attacking the crop, differences in pesticide use also occur between geographic regions.

The general trend in the number of corn acres treated with insecticide has been upward, but in recent years the rate of increase has slowed. From 1952 to 1966 the proportion of U. S. corn acreage treated increased from 1 to 33 percent [3]. In the ten years from 1966 to 1976 only an additional 5 percent was added to the treated acres [19]. The major reason for the leveling off of the trend relates to improved pest management strategies. Crop rotation, tillage systems and other cultural practices have been used to reduce the risk of insect loss. Also, scouting and other assessment techniques have provided an improved indication of potential yield loss and reduced excessive treatments. Table 8 shows the regional differences in use. Insecticides were most extensively used in the Northern Plains with 52 percent of the acres treated in 1976 and least extensively used in the Lake states with 36 percent treated. In the Corn Belt, the proportion treated was 39 percent, a six percent decrease from five years earlier.

Table 8. Percent of corn acreage treated with insecticides,
by Corn Belt, Lake and Northern Plains Regions,
1971 and 1976

Region	:	1971	:	1976	:	Change
	:		:		:	
	:	- - - - Percent of Acreage Treated				- - -
Corn Belt	:	45	:	39	:	-6
Lake	:	25	:	36	:	11
Northern Plains	:	43	:	52	:	9

Source: Reference nos. 3 and 19.

Major shifts have occurred in the kinds of insecticide applied to corn. In 1964 and 1966 aldrin was the most commonly used insecticide and accounted for over 60 percent of the total pounds of all insecticides applied to corn [3]. Aldrin was an effective treatment for many insect pests including corn rootworm but was suspended from use on field crops because of the toxic residues and potential buildup in animal tissues [14]. It has since been replaced by several other chemicals including carbofuran, phorate and dyfonate. In 1976, these three leading insecticides accounted for 65 percent of all insecticides applied to corn [19].

Soybeans are less prone to insect damage than corn, and the use of insecticides has been less extensive. In 1976, only seven percent of the U. S. soybean acreage was treated with insecticide and that treatment was mostly limited to the southeastern production regions [19]. Approximately 48 percent of the soybeans in the Southeast were treated for insect pests while in the Corn Belt and Delta Regions only 1 and 4 percent, respectively, received treatment. The period of the largest increase in use was between 1966 and 1971 when treated acres more than doubled. From 1971 to 1976 little change occurred in the number of treated acres but because of the increase in total acres, the proportion treated declined slightly. Toxaphene, methyl parathion and carbyl have continued to be the leading insecticides accounting for nearly 90% of all insecticides applied to soybeans [19].

Tillage Systems

The moldboard plow, which was used to break up the native prairie across much of today's corn and soybean production region more than a century ago, has long been considered to be a good farm management implement and essential for obtaining high yields. The inversion of the top few inches of soil buries crop residues; lets air into the soil; helps control weeds, insects and disease; mixes fertilizer into the soil and increases water infiltration. Recently, however, farmers have been adopting non-conventional tillage systems which do not include the moldboard plow. Because of high energy and time requirements associated with moldboard plowing, alternative systems offer the potential for cost and labor savings. In addition, tillage systems which leave crop residue on the surface reduce the hazards of wind and water erosion and conserve soil moisture by reducing surface evaporation. The

development of new disease resistant stock and agricultural chemicals to control weeds and insects has further reduced the need for moldboard plowing. Improved design in other tillage implements and planters has also supported the adoption of non-conventional tillage systems for corn and soybeans.

Trend data on the adoption of non-conventional tillage systems for corn and soybeans are not available for most states, but general indications are that an increasing number of acres are now planted without use of the moldboard plow. A statewide survey in Ohio conducted in 1979 reported 32 percent of the corn and 28 percent of the soybeans were planted using no tillage or conservation tillage systems [57]. The conservation tillage system was defined to exclude moldboard plowing but to include chisel plowing and disking in seedbed preparation. "No till" systems were defined to include tillage only in the seed zone area prior to planting. For corn, "no till" accounted for 9 percent of the total and for soybeans it accounted for 2 percent of the total. Prior to 1970, there was little use of other than conventional tillage systems for either crop. In the Ohio survey, wide differences occurred among counties in the level of adoption of these non-conventional systems. The proportion of acres planted without use of moldboard plowing ranged from almost none in several counties to three-fourths of the planted acreages in other counties. The Kentucky Crop and Livestock Reporting Service conducted a tillage practice survey in 1981 and reported 34 percent of the corn and 48 percent of the soybeans were planted with no tillage or minimum tillage systems [43]. Roughly three out of four Missouri farmers in 1978 were reported using chisel plowing instead of moldboard plowing [49].

Experimental research on yield impacts from the non-conventional tillages has had a wide range of results. A review of experimental studies on a number of Corn Belt soils suggests that both positive and negative responses can be associated with different systems and occur with both corn and soybeans. The interaction of tillage systems with soil and climate affect soil moisture, soil temperature, fertilizer and chemical placement, weed competition and other important factors which influence yield. Positive yield responses have been most often associated with well drained, medium textured soils and climates or weather with low precipitation. Negative yield responses have been most often associated with poorly drained, fine textured, and dark colored soils and with humid climates having short growing seasons.

In the Corn Belt states, soil texture and drainage is cited as important factors affecting yield with the adoption of non-conventional tillage systems which eliminate the moldboard plow and leave previous crop residues on the surface. Yields from continuous corn under "no till" on fine textured, poorly drained Ohio soils were 10 to 20 percent less than with a fall moldboard plowed, conventional tillage system [74]. On well drained soils, crop yields using "no till" systems were equal to yields from conventional systems. One Ohio study investigated the long term impact of continued use of a no tillage system and compared yields to a conventional system [75]. After five years in continuous corn, the non-conventional systems yielded 13 bushels per acre less on poorly drained clay soils, but 12 bushels per acre more on well drained sandy and silt loam soils [75]. In Iowa similar results were reported from a five-year study [50]. Mean yields were 8 bushels per acre in

favor of reduced tillage on Moody silt loam but 5 bushels per acre in favor of conventional tillage on Grundy silt loam. In Minnesota mixed yield impacts are also reported with the adoption of non-conventional tillage systems. On Webster clay loam in South Central Minnesota, the four year mean corn yield was 108 bushels per acre with no till compared to 130 bushels per acre with fall moldboard plowing [6]. Under dryer climate conditions in Southwestern and West Central Minnesota, however, mean corn yields were approximately the same with either system [7]. For a relatively dry study period at one Minnesota test site, slightly higher average corn yields were reported on "no till" plots.

For soybeans, similar yield impacts have been associated with the adoption of non-conventional tillages. Chisel plowing, disking and other reduced tillage systems have replaced moldboard plowing with little or no yield impact. "No till" systems, however, on certain soils have often resulted in yield reductions. A six year study (1967-72) of soybean yields on Ohio test sites reported a six to nine bushel yield advantage of moldboard plowing over "no till" on Crosby Silt Loam [74]. On the same test site with less effective weed control and lower plant populations, further yield reductions occurred. Four years of test results at the University of Missouri Fleetwood Farm showed a nine bushel per acre advantage to conventional over no tillage systems [55].

In Minnesota, a 1974-77 study of crop yields as affected by tillage practices reported a mean yield of 46 bushels per acre with fall moldboard plowing and 39 bushels per acre with continuous no till [6]. There was little yield impact with other reduced tillage systems or "no till" soybeans following corn which had been moldboard or chisel plowed in the preceding year. Based on one study, researchers have suggested that a five bushel per acre yield reduction be associated with "no till" as an average response compared to conventional tillage [29].

Double Cropping

Double cropping is the practice of producing two crops in sequence on the same acreage within one year. Until recently this practice has been limited to areas where the growing season lasted the entire year, but it is now being used in more temperate climates. Successful harvesting of two crops in a single growing season has been aided by the development of earlier maturing varieties, herbicides, irrigation, and the mechanization which allows interseeding or a quick harvest of the preceding crop and immediate planting of the second crop. Soybeans following small grains, often wheat, has been among the most successful double cropping systems. Corn, other than for silage, is generally not used in a double cropping system within the major U. S. production regions.

Double cropped soybeans are most common in the Southeast and Delta production regions, but in recent years they have been extending northward into the Corn Belt states. The extent of double cropped soybeans in recent years is indicated in Table 9. Although the data in Table 9 includes all planted soybeans, whether planted for beans or forage, it identifies those states where double cropping is of major importance. Over one-half of the soybeans grown in Georgia and one-third in Arkansas, North Carolina and South Carolina are doubled cropped.

Table 9. Percent of soybeans doubled cropped, selected states,
1978 to 1981

State	1978	1979	1980	1981
	- - - - - Percent - - - - -			
Ohio	1	1	0	1
Indiana	3	2	3	4
Illinois	2	2	3	7
Missouri	10	11	13	19
Arkansas	9	11	18	33
Louisiana	1	2	1	5
Mississippi	1	3	6	12
North Carolina	11	11	24	35
South Carolina	15	17	15	36
Georgia	26	23	38	52

Source: U. S. Department of Agriculture, Statistical Reporting Service.
(These data do not represent official estimates of the Crop Reporting Board
but are based on data as obtained from survey respondents.)

The yield difference between single and double cropped soybeans is generally not estimated on a statewide basis. However, in 1981 the Missouri Crop and Livestock Reporting Service forecast yields for both single and double cropped soybeans. In the Southeast Crop Reporting District where 42 percent of the state's double cropped soybeans were grown, they were forecast to yield eight bushels per acre less than single cropped soybeans. In the northwest district, the yield advantage to single cropped beans was 20 bushels per acre [52].

NATURAL RESOURCE DEVELOPMENTS INFLUENCING CORN AND SOYBEAN YIELDS

Historically natural resource developments have had an important role not only in bringing new lands into production, but also in enhancing potential yields on existing cropland. Major types of natural resource developments include artificial drainage, irrigation, soil conservation and flood protection. Each of these represent long run capital investments in land which improves or, in the case of soil conservation, prevents a reduction in productivity. These capital investments, however, may lose their effectiveness over time or become obsolete with new and improved techniques. As a consequence, the capital stock in natural resource development over a large area can change over time. Positive change occurs when gross investment exceeds depreciation and negative change occurs when depreciation on existing stock exceeds gross investments.

Reported in this section are limited data on drainage, irrigation, and soil conservation. Site specific yield impacts from these developments are also reported where empirical studies are available.

Drainage

Crop yields are harmed just as much by excessive moisture as by deficient soil moisture. In humid areas of the U. S., many soils have a wetness hazard which limits their use for agricultural production unless artificially drained. This wetness hazard results because the water table is near the surface, a suspended water table from a slowly permeable soil layer exists during a period of heavy precipitation, or the area is land locked with no natural outlet.

Artificial drainage enhances corn and soybean yields on wet soils for a number of reasons. It allows soils to dry earlier in the spring, resulting not only in earlier planting and a longer growing season, but also in a warmer soil during early growth stages. Drained soils have better aeration allowing more oxygen to plant roots. It also results in increased depth of rooting, making plants less susceptible to drought damage. Drier soils have also been shown to be more efficient in the use of nitrogen and phosphorus fertilizers, and have fewer weed and pest problems.

Prior to settlement it was necessary to install artificial drainage to remove excess water on much of the land in the Ohio, Mississippi and Great Lakes basins. Drainage activities and their impact on crop yields, however, did not stop with initial reclamation projects but have been a continuous process of maintenance and improvements. Gained knowledge about the soil moisture requirement of crops, water movement through different soils, and improved installation machinery and materials has allowed drainage systems to create more optimum soil moisture conditions for crop production.

Table 10 indicates the extent of 1977 cropland with soils having a wetness hazard and drainage treatment needs. Within the Corn Belt, 27 percent of all cropland has a wetness hazard associated with its use unless adequately treated. According to the National Resource Inventory [86], productivity could be improved on 19 percent of the cropland in the Corn Belt by improved drainage facilities. For the Delta states productivity could be improved on 30 percent of the cropland. Drainage treatment needs are less extensive in the Lake, Northern Plains and Southeastern Regions.

Table 10. Total cropland and cropland soils with wetness hazards and drainage treatment needs, Corn Belt, Lake, Northern Plains, Delta, and Southeast Regions, 1977

Region	Total cropland	Cropland with "wet" soils		Cropland with drainage needs	
	1000 Acres	1000 AC	(%)	1000 AC	(%)
Corn Belt	89,922	35,982	40	17,478	19
Lake	44,141	16,567	38	3,688	8
Northern Plains	67,661	5,440	8	691	1
Delta	21,191	15,715	74	6,304	30
Southeast	30,870	7,367	24	3,338	11

Source: Reference no. 86.

Trend data on drainage and its potential impact on crop yields are not generally available. Some drainage and drainage improvements are financed by private or non-federal investment and accomplished without Soil Conservation Service or District cooperation and are consequently not always recorded. Time series data, however, are available on those facilities installed with Soil Conservation District cooperation and assistance from the Soil Conservation Service. Figure 22 indicates the miles of open drainage systems installed annually with this public assistance in the Corn Belt, Delta and Lake states from 1964 to 1978. These data represent gross investment rather than net changes. To obtain a net change in drainage investment it would be necessary to estimate depreciation on existing facilities and subtract that amount from gross investments. Such a study of drainage was made at the national level and concludes that new investments have not kept pace with depreciation, and drainage systems are declining in their overall effectiveness [84]. This study reports a net reduction in drainage capital of about one-third of one percent annually since 1970. Although the number of miles of installed drainage illustrated in Figure 22 cannot be directly related to the net change in drained acres, it seems apparent there is a substantial reduction in the rate of installation of drainage systems.

Irrigation

As amount of precipitation decreases, irrigation becomes an increasingly important input for successful corn and soybean production. In areas where rainfall averages less than twenty-five inches per year, irrigation is almost essential to obtain profitable corn and soybean yields [56]. In these arid regions timing of application and quantity of water applied become important variables influencing yields. For the more humid areas, irrigation is used to supplement soil moisture during periods of rainfall deficiency. Irrigation or the potential to irrigate reduces the risk of low yields and permits the adoption of other high yield technology.

Corn

The largest acreages of irrigated corn as well as yield differences between irrigated and non-irrigated conditions occur in the Northern Plains Region. In 1980, the 5.9 million acres of irrigated corn in Kansas and Nebraska accounted for 70 percent of the total corn acreage and 84 percent of the production in these states. Since 1960, significant changes in both irrigated and non-irrigated acreage occurred in the Northern Plains. The changes are particularly notable in Nebraska as shown in Figure 23. In the short time from 1960 to 1965 non-irrigated corn acreage dropped from 5.0 million acres to 2.3 million acres, and the proportion of corn produced on irrigated land increased from 37 percent to 48 percent. From 1964 to 1980 the number of irrigated corn acres quadrupled while the number of non-irrigated acres remained stable. In 1980 the 5.0 million acres of irrigated corn produced 83 percent of the total corn production in Nebraska.

The major source for this irrigation water is the large Ogallala Aquifer which has a limited supply potential. Concern has been expressed about the continued growth of irrigation and the high energy requirement of pumping as the water table is drawn down [85]. Studies focusing on future changes in

Figure 22. Miles of open drainage systems installed annually, Corn Belt, Delta, and Lake Regions, 1964 to 1978.

Percent of 1967

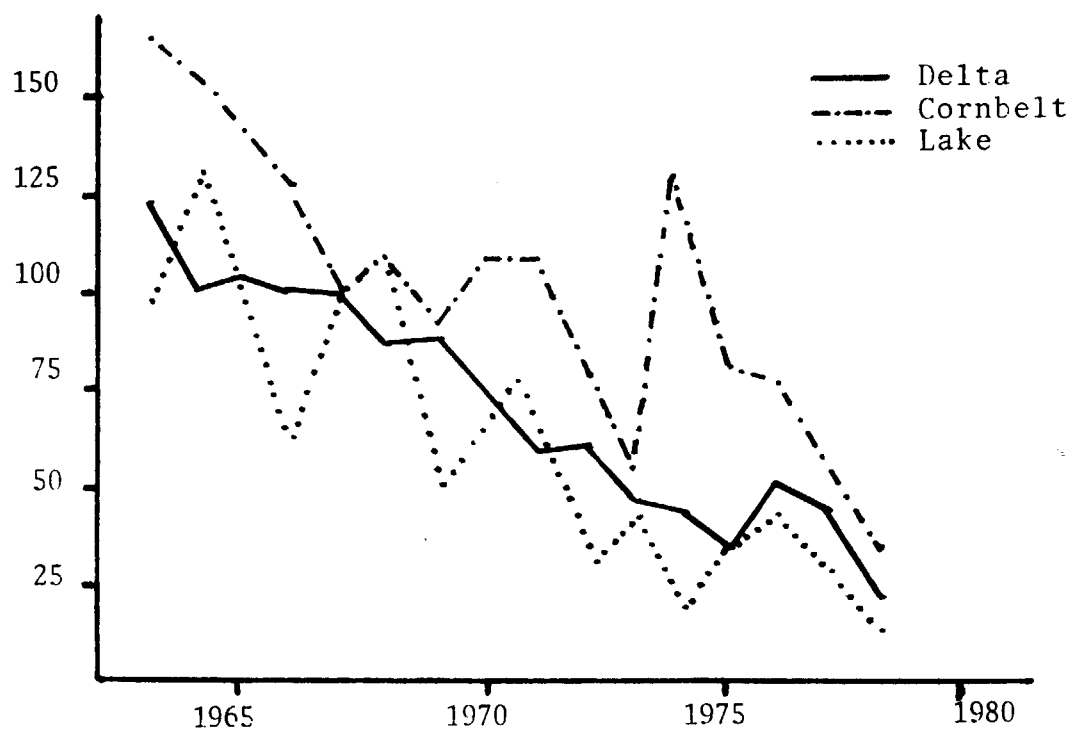
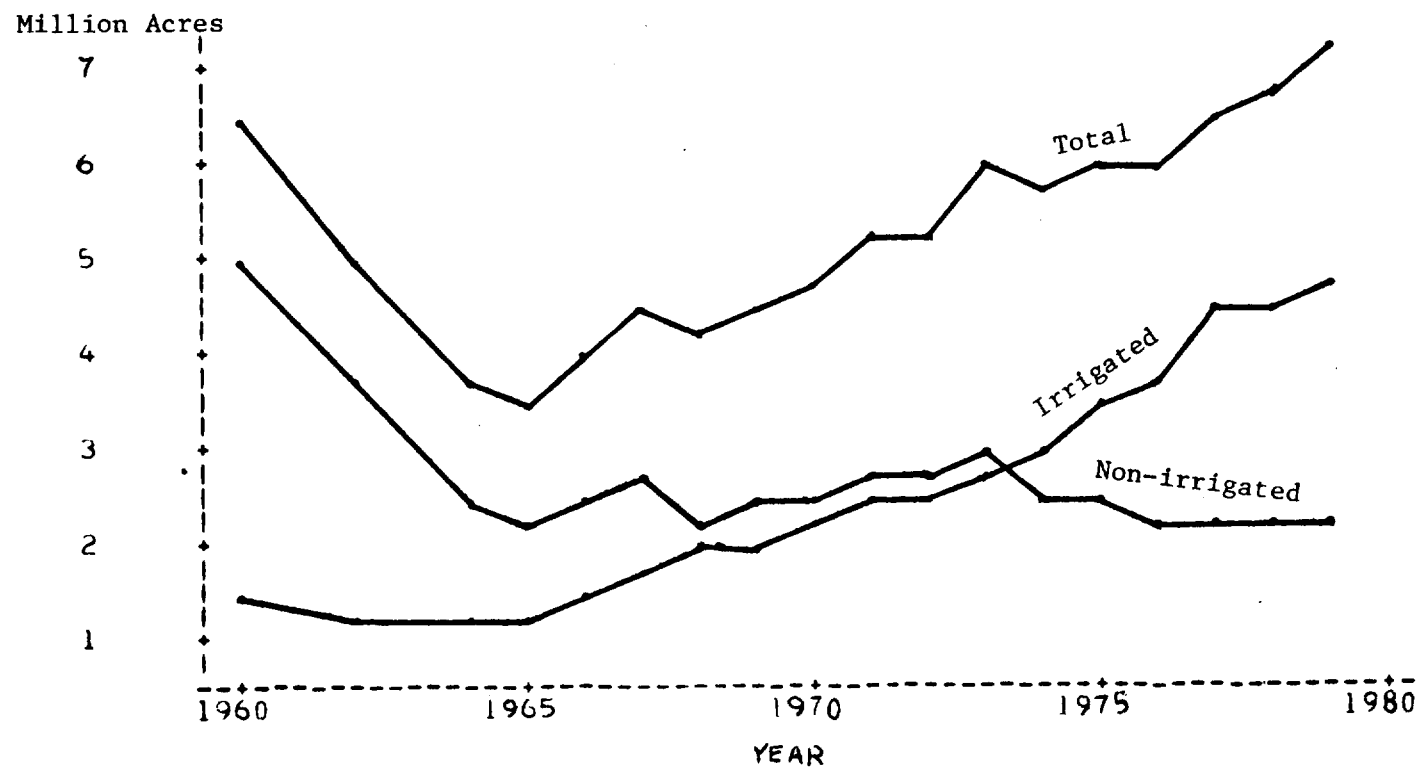


Figure 23. Irrigated and non-irrigated corn acres, Nebraska, 1960 to 1980.



irrigation from this aquifer predict that current levels can be maintained only until about the year 2000. These economic studies suggest that irrigated acreage has reached a maximum and will start declining during the 1980's [65].

Figure 24 illustrates the increasing extent of irrigated corn as one moves westward into the more arid regions of Nebraska and Kansas. In the western two-thirds of these states, corn produced under irrigated conditions accounts for 92 percent of the acreage and 97 percent of the production while in the eastern districts 48 percent of the acreage and 57 percent of the production comes from irrigated land. The yield differential between irrigated and non-irrigated corn also increases as one moves westward across the states. As illustrated in Figure 25, irrigated yields are quite similar in all of the crop reporting districts, but non-irrigated yields are substantially lower in the western districts. The yields shown in Figure 25 are the 1976 to 1979 mean yields. The yield difference between irrigated and non-irrigated corn ranges from 45 bushels per acre in southeastern Nebraska to 94 bushels per acre in southwestern Kansas.

The extent of irrigation in the other major corn producing regions is small relative to the total acreage. In the Corn Belt in 1978, less than 1 percent of the harvested corn acres was irrigated [88] and some of this acreage was for seed corn. Missouri has the most irrigated corn of the Corn Belt states with 138,000 acres accounting for over 6 percent of the state's corn acreage. In the Lake Region, 2.9 percent of the corn was grown on irrigated land. Although the total amount of irrigated land in the Corn Belt and Lake states increased nearly 2.5 times from 1974 to 1980 [37], it still accounts for a relatively small proportion of the total acres and consequently has had little impact on statewide or regional yields.

Because the irrigation of corn in the Corn Belt and Lake Regions is concentrated in a few areas, it potentially has had a yield impact in a few counties or Crop Reporting Districts. In Iowa about 70 percent of the irrigation is concentrated along the western tier of counties [55]. In Illinois the irrigation is concentrated in the northern one-third of the state along the valleys of the Illinois, Kankakee, Mississippi and Rock rivers [46]. In the Lake Region irrigated corn is concentrated in several areas where the soils have low soil moisture holding capacity and ground water supplies are relatively shallow.

The yield response of corn to irrigation in the Corn Belt and Lake Regions varies according to soil type and other technological factors which are often associated with irrigation as well as with the amount of precipitation. When irrigation facilities are available to provide extra water should stress conditions occur, it permits the adoption of high fertilization and plant populations necessary for high yields. Consequently, the observed yield response from irrigation also includes the impact of several yield increasing technologies. A 1980 survey of Missouri farmers who irrigate indicated an average difference of 50 bushels per acre between irrigated and non-irrigated corn [33]. This yield response was reported to be approximately the same over the preceding four years. In the Central Clay Pan area of Missouri, the nine year mean yield difference reported from a survey in Audrain and Callaway counties was 58 bushels per acre [33]. In a five year experiment on an Iowa sandy soil, the mean yield increase from irrigation was

Figure 24. Percent of corn production grown under irrigation by crop reporting districts, Nebraska and Kansas, 1979.

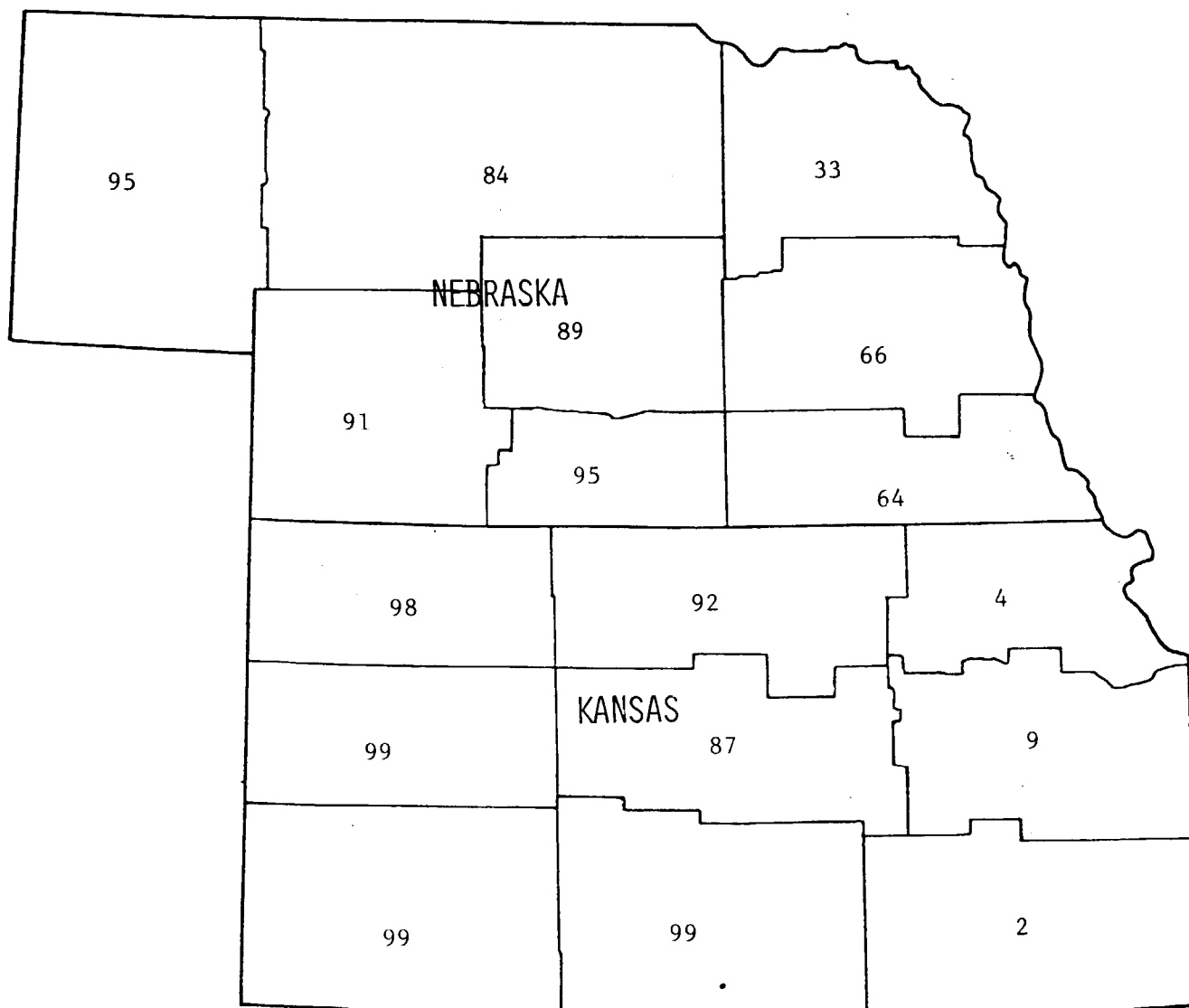
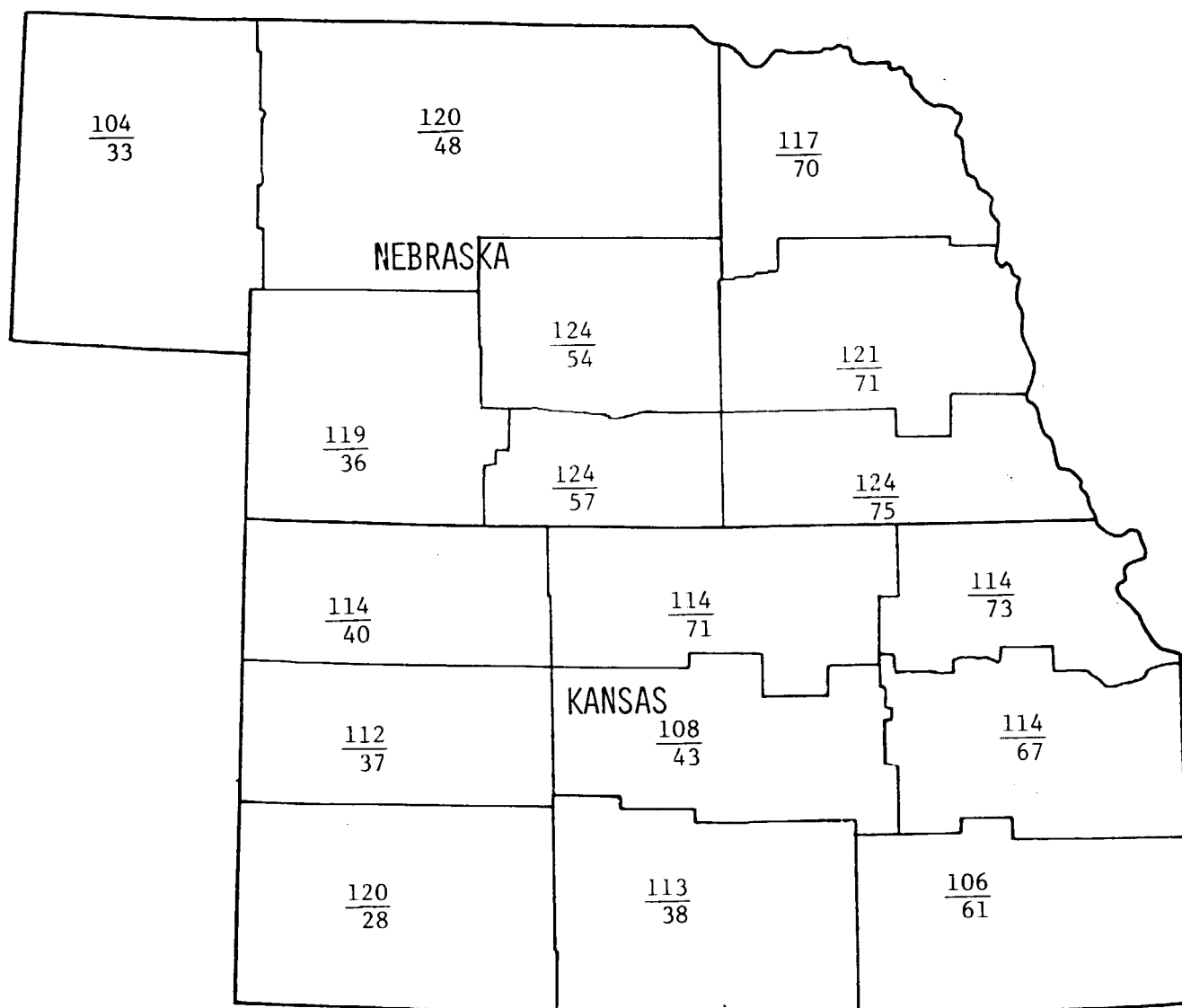


Figure 25. Irrigated and non-irrigated mean corn yields (bushels per acre) by crop reporting districts, Nebraska and Kansas, 1976-79



Top number is irrigated yield in bushels per acre.

Bottom number is non-irrigated yield in bushels per acre.

34 bushels per acre [66]. An eight year Iowa study on a higher water holding silt loam soil had only a 22 bushel per acre yield increase with irrigation [56].

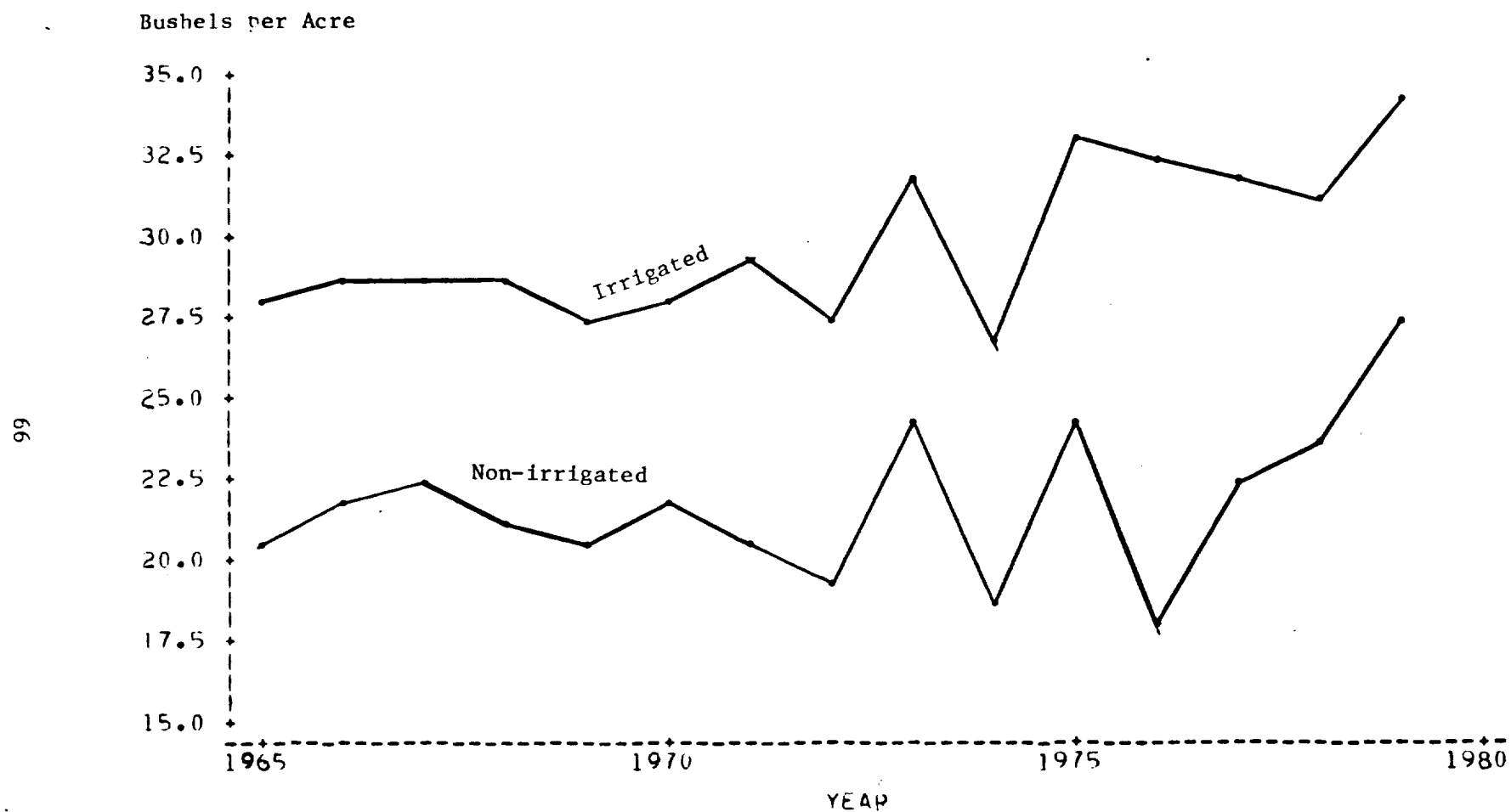
Irrigated soybeans are most common in the Delta Region, particularly in Arkansas. In 1978, 10.8 percent of the Arkansas soybeans were grown on irrigated land [88]. In the Corn Belt and Southeast regions, less than one percent of the soybeans is irrigated. Of the irrigated soybeans in the Southeast Region, about 75 percent are grown in Georgia. In the Corn Belt, irrigated soybeans are most common in Missouri where about 2 percent are grown on irrigated land. Irrigated soybean acreage is concentrated within a few counties or Crop Reporting Districts. In Missouri, irrigation is most prevalent in the southeastern bootheel area; however, it has been expanding into the Central clay pay area where soils have a low water holding capacity and surface water can be impounded for irrigation. In the other Corn Belt states less than 0.5 percent of the soybean acreage is irrigated. Irrigated soybeans in Arkansas are primarily limited to the eastern Crop Reporting Districts.

The greatest yield response to soybeans occurs on soils with low water holding capacity and in areas of low precipitation. Also, the yield difference between irrigated and non-irrigated soybeans reflects the adoption of other yield increasing technologies along with irrigation. The yield difference between irrigated and non-irrigated soybeans in Arkansas is illustrated in Figure 26. The mean yield difference between irrigated and non-irrigated soybeans from 1965 to 1979 was 8.1 bushels per acre. In Missouri the nine-year mean yield difference reported by irrigators in Audrain and Callaway counties was 14 bushels per acre [33]. In that survey the 1980 yield response from irrigation for double cropped soybeans was 12 bushels per acre and for single cropped soybeans it was 15 bushels per acre. Similar yield responses of single and double cropped soybeans to irrigation were reported in each of the preceding four years.

Soil Conservation

Soil depletion by wind and water erosion has a negative impact on crop yields unless abatement practices are applied to keep the productive top soils in place. Higher fertilization and other yield increasing technology have often masked the negative effects from the gradual wearing away of surface soils. Although little data are available on the yield impacts from soil depletion, it is reported that since 1935 approximately 100 million acres of U.S. cropland have been depleted to the point they can no longer be economically cultivated and that on an additional 100 million acres, more than 50 percent of the top soil has been lost [13]. The 1977 National Resource Inventory revealed that 97 million acres or 27 percent of the nation's cropland experience erosion rates that exceed five tons per acre per year [86]. Soil loss tolerance levels have been established to indicate the maximum rate which may occur without having a long run loss in agricultural productivity. These tolerance levels vary by soil but generally range from 2 to 5 tons per acre per year.

Figure 26. Irrigated and non-irrigated soybean yields, Arkansas, 1965 to 1979.



Source: Arkansas Crop and Livestock Reporting Service, Little Rock, Arkansas.

Table 11 indicates the proportion of cropland in the major corn and soybean production regions within four ranges of soil loss rates. In the Corn Belt it was estimated that 38 percent of the cropland soil was being depleted (losses in excess of five tons per year) with the types of farming practices used in 1977. In the Southeast and Delta, soil depletion is reported to be occurring on at least 45 and 52 percent of the crop land, respectively. Because of the flat topography in the Lake Region and low precipitation in the Northern Plains Region, soil depletion is somewhat less of a problem.

Table 11. Soil erosion rates on cropland, Corn Belt, Lake, Northern Plains, Delta and Southeast Regions, 1977

Production region	:	:	Erosion Rates (tons/ac/yr)			
			<2	: 2-5	: 5-10	: >10
	:	Cropland				
	:	1000 Ac	- - - - Percent of Total - - - - -			
Corn Belt	:	89,922	28.5	33.6	19.7	18.2
Northern Plains	:	67,661	49.4	33.0	9.8	7.9
Lake	:	44,141	65.9	21.3	7.8	5.0
Delta	:	21,191	12.5	35.4	34.7	17.4
Southeast	:	30,870	28.1	26.8	23.4	21.7

Source: Reference no. 86.

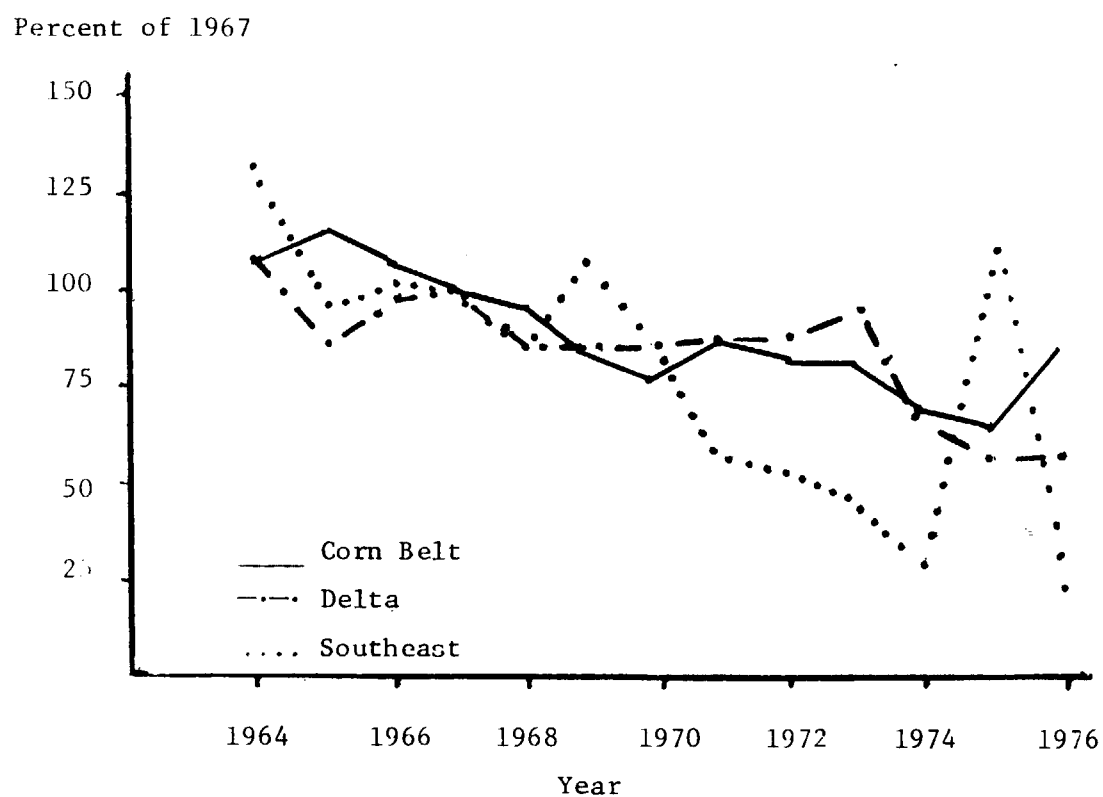
The crop yield impacts from soil depletion have not been broadly studied and are difficult to measure. Yields are least affected on soils having subsoils similar to the surface layer. However, for many soils the properties of subsoils are quite different and less favorable for plant growth and this results in lower yields. Erosion phase classes have been used to describe soil erosion conditions and to predict yield impacts [64]. Phase I condition includes soils with a deep "A" horizon in which little mixing of "B" horizon occurs in the normal plow layer. Phase II condition exists when there is a mixing of "A" and "B" soil horizons within the plow layer and phase III exists when the plow layer consists mostly of B horizon soil constituents. In a Southern Iowa River Basin study average corn yield reductions of 16 and 23 bushels per acre were associated with changes from phase I to phase II and to phase III, respectively [64]. For soybeans the yield reductions of 5 and 8 bushels per acre were associated with these shifts in erosion phase. These yield reductions were estimated to occur even with higher fertilization rates to offset the nutrient loss from erosion.

One of the objectives of the Southern Iowa study was to predict a future date when specific soils will shift from one phase to another, assuming continuation of current cropping systems and conservation practices. It was estimated that by the year 2020, 26 percent of the basin's cropland currently in phase I would deplete to phase II or III, and 20 percent of the cropland currently in phase II would deplete to phase III. Over this time period the amount of cropland in phase III would increase from 9 to 39 percent. As a

consequence, yield reductions for corn of 16 to 23 bushels per acre (for soybeans 5 to 8 bushels per acre) from a normal trend are predicted on 30 percent of the cropland over a forty year period.

Trend data on soil depletion and its impact on productivity are not available. Time series data are limited to the amount of land served by certain soil conservation practices accomplished under various federal programs. Acres of contour farming reported as accomplishments of the Agricultural Conservation Program are illustrated in Figure 27. Although contour farming does not necessarily prevent soil depletion, it is the most often recommended practice to reduce soil erosion on tilled cropland. These data represent only the new practices in place on the land. Just as contour farming can easily be adopted, it can also be abandoned to accommodate larger machinery, field expansion or many other desires of farm managers. Consequently, practices often remain in place for only a short number of years before they are abandoned and erosion rates return to excessive levels. From Figure 27 it is evident that the trend in new investment in the basic soil conservation practice of contouring is declining in the three regions having the greatest soil erosion hazards. This trend is consistent with a national study of soil and water conservation which suggests that capital improvement for conservation has been deteriorating since 1955 [84]. This study reports a decline in capital investment of 1.1 percent each year from 1955 to 1970 and 2 percent per year from 1970 to 1975.

Figure 27. Acres of contour farming applied annually, Corn Belt, Delta and Southeast Regions, 1964 to 1976.



Source: Reference no. 80.

NEEDS FOR FURTHER STUDY

Lack of information about the adoption of technology and its influence on yield has been identified as a problem in yield model development. If trend as a surrogate variable for technology is to be more precisely specified or replaced by causal factors in regression type yield models, then the yield responses to important technology factors must be estimated. This information is needed for the years and areas used to develop the model. Furthermore, in order to make yield forecasts from the model, it is necessary to predict the effect and use of the technological factors included in the model.

Production inputs, cultural practices and natural resource developments thought to have important influences on U.S. corn and soybean yields are identified earlier in this report. Results of experimental research studies are cited as a measure of the potential yield difference between the use and non-use of specific technologies. Available farm survey data on the estimated adoption or rate of use of these technologies in the major U. S. corn and soybean production regions are discussed. The results are also reported from limited research focusing on the aggregate yield effect from both the development and adoption of selected technological factors.

This literature survey suggests the following needs for further study to assess the independent influence of technology on past crop yields and to monitor and forecast the influence of emerging technologies:

Obtain an improved soil fertility indication. Changes in soil fertility are identified as an important factor influencing both corn and soybean yields. The adoption and use of larger applications of commercial fertilizers have been a major factor affecting soil fertility levels. The reported data since 1964 indicate a general upward trend in the use of all nutrients in all major production regions. However, over that time period, there have been plateau periods and year to year fluctuations. It can be anticipated that similar year to year fluctuations will continue as farmers make their management decisions based on changing prices and agricultural policies. Besides commercial fertilizer applications, other factors such as previous crop, soil type and weather can cause year to year changes in soil fertility levels.

It is widely recommended that farmers base their commercial fertilizer applications on soil testing results and that they apply first the recommended rates to build up the soil nutrient pool in the field to a desired level and then apply maintenance rates accounting for soil nutrient gains and losses from all sources. A similar accounting technique to that used at the field level to estimate nutrient gains and losses may be used to estimate changes in the soil fertility level over large areas. This may provide a better indicator for use in yield model development than merely using the amount of commercial fertilizer nutrients applied per planted acre. With information about applied commercial fertilizer, weather and previous crop yield, gains and losses in the soil nutrient pool may be estimated. With such an accounting technique and price information, it would also be feasible to make forecasts of potential changes in the soil nutrient pool.

Estimate and forecast the continuing genetic improvements in corn and soybeans. New soybean varieties have continued to be developed and adopted. Several years and locations of yield performance test data on specific soybean varieties, as well as farm survey data on the adopted varieties, are available to assess yield improvements in the last thirty years. For corn, hybridization was hailed as a major innovation contributing significantly to corn yield increases during the 1940's and 1950's. Various studies of the influence of hybridization and a yield improvement index prior to 1961 were reported earlier in this report. The influence of continuing genetic improvements, since that time, however, is not as well documented. Although much data are available from yield performance tests on the yield differences among the many available hybrids, data are not readily available from farm surveys or seed distributors on the adopted hybrids. Also because recent genetic improvements have focused on developing plants which respond to specific cultural practices (tillage systems, irrigation, pesticide use, plant density and fertilization levels), it has become difficult to sort out the independent contribution of genetic improvement from the changes due to the simultaneous adoption of these cultural practices.

Measure the yield influence from herbicide use and the resulting changes in cultural practices. Although some yield gains were cited in experimental research from chemical over mechanical weed control methods, the yield influences of complementary cultural practices feasible only with chemical weed control may also be of significance. Conservation tillage systems were identified as a recent technology being adopted on corn and soybean fields. Limited research suggests that yield differences do occur between different tillage systems and these differences vary by soil types and weather. Because of differences in production costs, the highest yielding tillage system is not necessarily the most profitable or commonly adopted system. An emerging cultural practice for soybeans, made possible by chemical weed control, is solid seeding. Higher plant populations and more equal distant spacing between plants have increased soybean performance test yields over conventional row planting. Another emerging technology for soybeans is double cropping. Although yield reductions are associated with this technology, it is becoming a common practice in the Southeast and Delta production regions and extends into southern areas of the Corn Belt.

Assess the yield influence from changes in natural resource developments of irrigation, drainage and soil conservation. Although the year to year changes in the accumulated capital investment in these natural resource developments are quite small, the long term changes and potential influences on regional corn and soybean yields may be quite significant. The efficiency of drainage systems changes with the depreciation and replacement of existing facilities. Declines in the net capital invested for drainage systems occurred during the 1970's as well as changes in agricultural policy to subsidize these activities. The adoption of soil conserving practices can have an immediate influence on yields while the reduction in soil depletion can have long term effects. In the more arid production regions of the Northern Plains or Delta, acreages and yield differences between irrigated and non-irrigated corn and soybeans are generally available for yield model development. In the more humid areas of the Corn Belt and Lake Regions, however, irrigation has been adopted recently to reduce the risk of low yields in years of unusually low precipitation.

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